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SULPHURETS:

WHAT THEY ARE,

HOW CONCENTRATED, HOW ASSAYED, AND HOW WORKED:

WITH A CHAPTER ON THE

BLOW-PIPE ASSAY OF MINERALS.

BY WM. BARSTOW, M. D.

A. ROMAN AND COMPANY,
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PREFACE.

The subject of "sulphurets" is one which is of late attracting especial attention. These compounds are so intimately associated with the precious metals, that the intelligent working of those metals involves an acquaintance with the various conditions under which they are so associated, and with the various modes of treatment applicable to those conditions. The complete mastery of the subject is the study of a lifetime,—involving, as it does, a thorough study of chemistry and of mineralogy;—nevertheless, sufficient insight into it can be gained, without much difficulty, to be of great practical advantage to a Californian.

The object of this little book is to give the reader some idea of the matter in a simple and compact form; and save him the trouble of wading through a library of volumes, containing a mass of facts and instructions, diffusely stated and often vaguely expressed. There are many thinkers among the mining population, who would gladly avail themselves of an opportunity to acquire some definite information upon the subject; but, confused by the multitude of books for sale, which treat in general terms upon this class of subjects, they are discouraged from making a commencement.

There is no reason why the intelligent miner should not make his own assays, and determine for himself how to work his own

ores. It is hoped that this work may serve the purpose of giving a "start" to such. In it, clearness and conciseness of language have been aimed at. Technical terms have, as far as possible, been avoided. Nothing is said of the different proportions of sulphur in the various sulphurets, nor of other differences in the chemical constitution of the ores; lest the matter be unnecessarily complicated,—and the object of the book defeated. The wish has been to give practical details, rather than theory. The reader may perhaps have a desire awakened for the perusal of more extensive and elaborate works upon the subject; while at the same time he may become more capable of making a judicious selection among those works.

The author would here acknowledge his indebtedness, for many hints and suggestions, to the following works, viz: *Overman's "Treatise on Metallurgy," Goodyear's Translation of Bodeman & Kerl on Assaying," Kustel's Processes of Gold and Silver Extraction," Phillips on the Working of Auriferous Ores, Mitchell's "Practical Assaying," Muspratt's Translation of "Plattner on the Blow-pipe,"* and *Elderhorst's "Blow-pipe Analysis."* He would recommend those books to those who desire to pursue the subject.

All the apparatus necessary for making the experiments alluded to in the book, may be obtained in this city at moderate rates. B

San Francisco, October 25th, 1867.

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PART I.

WHAT SULPHURETS ARE.

Sulphurets, or sulphides,* are composed of sulphur and some other substance in *direct* chemical combination. They differ from *sulphates*,—with which they are often confounded by persons ignorant of chemical nomenclature,—inasmuch as that the latter are composed of *sulphuric acid* and the *oxyd* of the other substance. Thus, for example, common iron pyrites is a *sulphuret* of iron,—consisting of *sulphur* and *metallic iron*; while green vitriol, or copperas, is a *sulphate* of iron,—consisting of *sulphuric acid* in combination with the *oxyd* of iron.

All sulphurets may be decomposed by exposure to the action of the air, with the assistance of heat. Sulphuric acid is formed by the union of the oxygen of the air with sulphur, and the *sulphuret* is changed into a *sulphate*, and this is in its turn changed into an *oxyd*,—unless it is capable of supporting the heat to which it is

* Although the term "*sulphide*" is now coming into use, in conformity with *chloride*, *iodide*, etc., we shall in this work retain the older word, *sulphuret*.

subjected. This *oxyd* is itself, in some cases, decomposed by heat, leaving the pure *metal.*

The *metallic* sulphurets are the only ones with which we will concern ourselves. Of these, those which occur most abundantly in nature are the sulphurets of iron, copper, lead, zinc, silver, mercury, and antimony. Those of iron are the most abundant of all; that metal being more universally distributed, and having a greater affinity for sulphur, than any other. These two substances combine in all proportions.

It is probable that the sulphurets of iron are the source of most of the gold. Most gold-bearing rocks are colored by the oxyd of iron, and that oxyd is often plainly derived from decomposed pyrites, or sulphuret of iron, which is found very generally to be associated with gold, although not chemically combined with it. This discoloration is perceptible only above the "water-line," as it is termed;—that is, above the depth to which air and moisture can penetrate. This depth is variable; being determined chiefly by the hardness or softness of the rock containing the vein. The decomposition seems to extend to a greater depth in gold-bearing pyrites, than in that which is barren; the gold having but slight affinity for sulphur, moisture is to some extent permitted to find its way between the particles.

It should be added, however, that gold is often found in rock which not only contains no pyrites, but is also perfectly free from discoloration.

Quartz has been generally considered to be the matrix of the gold-bearing sulphurets; but it is not always so. There is abundance of evidence that they occur in other rocks. They are reported in Australia as in veins of

the "country rock," some distance from any quartz. A paper from Professor Silliman, read a short time since before the California Academy of Natural Sciences, describes beds of decomposed gold-bearing iron and copper sulphurets occurring at Whiskey Hill in Placer county, and at Quail Hill in Calaveras county, California. These are "ochraceous," and were originally to all appearance talcose and chloritic schists with mica; in places taking the character of veins, and parallel to the others in the region, in strike and dip. At Quail Hill the mass is three hundred feet wide. Both places were first opened for copper; the indications of that metal being distinct. Gold and silver are found in both. Prof. Silliman's experiments show results as high as $35 gold, and $15 silver,=$50—to the ton.

In North Carolina, gold is found in the sulphurets associated with the slates; and also, indeed, in the slate itself,—in the latter case perhaps set free by the decomposition of sulphurets. The San Juan del Rey mine, in Brazil, is also said to be in rock similar to that at Whiskey Hill.

We will now give a short list of the sulphurets which are more particularly objects of interest to the miner.

SULPHURETS OF IRON.—*Common Iron Pyrites;*
White do. do.
Magnetic do. do.
Arsenical do. do.—
(Mispickel.)

The first of these occurs generally in *cubes*. It is of a brass-yellow color, and so hard as not to be easily scratched with a knife.

The second is of a lighter yellow color,—sometimes grayish, or greenish. The crystals are *prisms;* and are frequently found in radiated masses.

The third resembles the first, except that it is not so hard, and is slightly attracted by the magnet.

The fourth is combined with arsenic. It is of a silvery-white color, and brittle.

SULPHURETS OF COPPER.—*Common Copper Pyrites;*
Purple Copper,—
(Erubescite);
Copper Glance;
Gray Copper.

The first of these is the most common of all the copper ores. It is a combination of sulphuret of copper and sulphuret of iron. It is of a brass-yellow color. and is easily scratched with a knife. It often becomes iridescent upon the surface, when exposed to a moist atmosphere. It is generally found *massive.*

Erubescite, or *Purple Copper,* is, when massive, of a reddish-brown color. After being exposed to the air, it changes to various shades of blue and red.

The next, *Copper Glance,* is of a lead-gray color,—with sometimes a bluish tint on the surface. It is still softer than the pyrites.

Gray Copper is of a grayish-black color, and contains iron, zinc, antimony and arsenic; with frequently silver and mercury.

SULPHURET OF LEAD.—*Galena.*

This well-known mineral is the chief ore of lead. It is lead-gray in color. The crystals easily cleave, or

split, into cubes. It is always associated with silver; and often with zinc, arsenic and iron.

SULPHURET OF ZINC.—*Zinc Blende.*

This ore varies in color according to the association of other metals with it. When, for instance, with iron, it is black;—with lead, it is reddish. It is sometimes green, brown, or yellow. It cleaves in plates.

SULPHURETS OF SILVER.—*Silver Glance;*
Ruby Silver;
Brittle Silver Ore,—
(Stephanite).

Silver Glance is in color blackish lead-gray. It is soft; can be cut like lead with a knife. Being in this respect unlike other minerals of the same appearance, it is easily distinguished from them. It contains eighty-seven per cent. of silver.

Ruby Silver crystallizes in transparent prisms of a ruby-red color. It is associated with antimony, in the proportion of fifty-eight per cent. silver, to twenty-three of the latter metal.

Brittle Silver Ore is very much like silver glance in appearance; though darker in color, and very brittle. This also is associated with antimony. It contains seventy per cent. of silver.

SULPHURET OF MERCURY.—*Cinnabar.*

This mineral is the source of most of the quicksilver of commerce. It is of a brown-red color, often streaked with scarlet. It occurs in small flat crystals, or massive.

SULPHURET OF ANTIMONY.—*Gray Antimony,—(Stibnite).*

This mineral is a ter-sulphuret of antimony. It is bluish-white in color, and brittle; consisting of small needle-like crystals.

These metallic sulphurets, thus briefly noticed, are those which will be most frequently brought to the attention of the miner. There are other ores of all these metals; but our subject is "sulphurets," and our limits will scarcely admit of even the mention of other ores.

PART II.

HOW SULPHURETS ARE ASSAYED.

This subject divides itself into two parts. The first has reference to the determining the *presence* of a sulphuret,—that is to say, the ascertaining the *character* of any specimen to be tested; the second to determining its *value*,—or the amount of metal associated with any given weight of it. The first is termed *qualitative*,—the second, *quantitative*,—analysis or assay.

Of each there are two methods,—the *dry* and the *wet*. In the first of these methods, the mineral to be tested is *melted*, by the aid of fluxes, into a single button of metal, the component parts of which are then determined by processes to be hereafter described. In the second, the mineral is *dissolved* by means of acids, etc., and the component parts of the solution determined by *precipitation* with various chemicals. The two methods are sometimes combined;—that is to say, a part of the work is done in the dry way, and the operation then completed in the wet way.

It would be impossible to give, in this work, anything like full notes upon *qualitative* assay. We can only

give a few hints introductory to the subject, for the benefit of those who may wish to pursue it more minutely, in a chapter on the blow-pipe at the end of the book. Assuming, then, that the reader has become sufficiently acquainted with the most common sulphurets, the general appearance and physical properties of which we have described, to be able to recognize them, we will go on to

QUANTITATIVE ANALYSIS.

This, as we have said, can be done either in the wet or the dry way. As, for most ores, the dry is, on the whole, preferable,--since, while giving sufficiently accurate results, it requires less scientific knowledge and less elaborate apparatus, besides taking much less time,—we shall dwell chiefly upon that.

DRY METHOD.—Assays by this method can be made either with the blow-pipe or with the crucible. But the test made with the former must necessarily be upon a very small quantity of ore; so small that the resulting button of metal would scarcely be perceptible, where the ore, although, perhaps, well worth working, is of only moderate richness. And as this is the case with the greater portion of our ores, and as the object of this book is to present to the reader, in as concise form as possible, a method of testing ores which shall be of immediate practical use to him, we shall speak more particularly of the crucible assay,—deferring our remarks upon the use of the blow-pipe to the chapter promised above.

CRUCIBLE ASSAY FOR GOLD AND SILVER.

Gold in ores is always alloyed with more or less of silver. In an assay of an ore, the general method of procedure is the same, up to a certain point, whether it is one of gold or silver; the additional step, in the case of the gold ore, being the separating of the gold from the silver,—or "*parting*," as it is termed. This is done by boiling in nitric acid, which dissolves the silver, but leaves the gold untouched.

We will commence with a specimen of ore not wholly made up of sulphurets, in which, although we expect to find a proportion of gold, the silver nevertheless predominates. It will serve as a guide, in general terms, for both gold and silver assays; although the proportion of fluxes, etc., must be varied in different cases, according to the suspected or ascertained composition of the ore. On this point we shall speak more fully in another page.

It is understood that we mean *troy* weight in all cases where it is not otherwise specified.

Half an ounce of the finely pulverized and sifted ore is mixed intimately with two ounces litharge, sixty grains borax-glass,* one ounce dry carbonate of soda, and five grains of finely-powdered charcoal. The mixture is put into a "Hessian" or clay crucible, of such a size as to be only half filled by it. A layer of common salt, about one-quarter of an inch in depth, being added, as a covering for the surface, it is ready for the furnace.

An *air*, or *draft* furnace, can be built at a very small cost by any of our readers who wish to make many

*This, with other points, is explained farther on, under the head of "Additional Notes."

experiments of the kind we are describing. It is a brick structure, some three feet in height and breadth, with a cavity one foot square and eighteen inches deep to the grate-bars, under which is the ash-pit, with its opening at the front for the draft. It can be built against any chimney of fifteen or twenty feet in height, with an opening of three by twelve inches to connect the two; or, a chimney can be extemporized with stove-pipe. If the furnace is expected to last for any length of time, it should be lined with fire-brick.

But in default of such a furnace, a common blacksmith's forge will answer the purpose. A few bricks can be set up in such a way that they will serve as a temporary furnace-wall. The crucible, with its contents, is placed within this wall, upon a half-brick, which furnishes a firm foundation, so that it will maintain its upright position; and the space between it and the wall is filled in with charcoal, which is also piled above it. The fire is lighted at the top, and the blast applied; moderately at first,—then more strongly. When the fusion is complete, which will be perhaps in the course of an hour, the crucible is lifted out with tongs, set in a warm place upon the floor,—a few taps being given it to gather together the particles of metal which still remain in the slag,—and allowed to cool. It is then broken; and the button of metal in the bottom, freed from slag by light blows with a hammer, is ready for the next process,—that of

CUPELLATION.—This process consists in a second melting, in a small, shallow, porous crucible, made of white bone-ashes moistened with water, moulded into

shape and dried. It is one of the oldest, most interesting, and most perfect processes in metallurgy. It is based upon these facts, viz.: that when lead is heated in a current of air, it easily oxydizes; that the resulting oxyd is fusible; that it readily yields a portion of its oxygen to copper or other oxydizable metals which may be present in fusion; and that if the arrangement is such that it can pass off, it takes these other oxyds with it. The porous substance of the small crucible, or "cupel,"—"little cup,"—serves the purpose of absorbing these oxyds; and the precious metal remains in a button by itself without loss.

The button which we have in hand is chiefly lead, derived from the litharge. The metal in the ore under examination, whether gold, silver, or copper, is intimately mixed with this lead.

The operation is performed in a furnace of peculiar construction; the essential part of which is the "muffle." This is an oblong box of fire clay, open at one end, and having an arched roof. It is about ten inches in length by five in breadth. It is so placed in the furnace that the burning coal completely surrounds it; and its floor being perfectly level, the little cupels upon it, with their contents, are safe from accident, and are easily handled.

This operation, too, can be performed in a common forge. A temporary brick wall, as before said, can in a few minutes be set up, in which the muffle can be placed, and surrounded with charcoal. The fire is kindled beneath the muffle; but the coal must be so replenished as to keep its top rather the hottest; as the oxydation and evaporation of the lead is caused by reflection from the roof.

If a muffle is not to be had, a large crucible may be made to serve the purpose. A hole must be pierced in the bottom, to admit of a circulation of air. Care must be taken, lest it be tilted to one side, and the assay be lost.

When the cupel is white-hot, the button, after being held over it for a short time, is placed upon it. It quickly melts; and soon begins to "drive," as it is called,—that is, to exhibit a movement upon its surface from the center towards the edge, as in *boiling*. As soon as this is perceived, the heat must be lowered as much as is possible without stopping the motion; for the oxyd of lead is now being formed and absorbed, and if the temperature is too high, more or less silver will be absorbed with it. If, on the other hand, it is too *low*, the "driving" stops, the assay "freezes," and is likely to be incorrect. A good guide for its management in this respect, is *the position of the lead fumes*. They should rise to about the middle of the muffle. If it is too hot, they scarcely rise above the cupel; if too cold, they rise to the top of the muffle. When the temperature is right, a ring of small crystals of litharge forms on the side of the cupel; this is another guide. The temperature is controlled by opening or closing the draft-hole, and by placing pieces of coal at the mouth of the muffle. Several assays are usually cupelled at the same time; as it is as easy to watch a larger number as a single one. In case the cupels at the back part of the muffle should become too hot, a "cooling-iron" is introduced. This is a flat piece of iron, two or three inches square and half an inch thick, furnished with an iron handle.

The heat must be increased towards the end of the operation, because the button becomes less fusible as the proportion of lead which it contains is diminished. Constantly in motion, it gradually lessens in size, until the lead is entirely expelled; when, with a peculiar *gleam*, easily recognized if once seen,—it suddenly "brightens,"—as it is called. Just before this, a beautiful play of rainbow colors announces the formation and departure of the last thin coating of litharge, through which the light strikes the silver button, and is reflected unequally from the different parts of its surface.

The cupel is now drawn towards the mouth of the muffle, and allowed to cool gradually and thoroughly. The button,—if the operation has succeeded completely,—is perfectly bright, and rounded in shape; and is easily loosened from the cupel.

It is now ready for weighing. By this operation is determined the total amount of metal,—that is, of gold and silver,—in the ore tested; and from this we may estimate the amount of metal in a ton. The following is a simple method of making the calculation:

We will suppose the button to weigh exactly *one grain*. This is the yield of half a troy ounce of ore. In one ton of 2,000 avoirdupois pounds, there are 29,166+troy ounces.* There are, of course, *twice* that number of *half* ounces=58,333. This, then, is the number of *grains* of metal in a ton of the ore we have been testing. It is equal to 121.5 troy *ounces*. We may therefore construct the following *rule* for cases

*The troy pound is 5,760 grains; the avoirdupois, 7,000 grains; the troy ounce, 480 grains.

Where half a troy ounce is taken for the assay sample.

RULE.—Multiply the weight of the button in grains and decimals of a grain by 121.5. The product will be, in troy ounces and decimals of an ounce, the amount of metal in one ton of ore of 2,000 avoirdupois pounds.

It is plain, that if *double* the amount is taken as the assay sample, the multiplier must be *one-half* as large. Thus, for one ounce, the multiplier is 60.75; for two ounces, 30.37; four ounces, 15.18; eight ounces, 7.59; and so on.

ASSAY BALANCE.—We will now describe a very simple balance which the reader can easily construct for himself, and which will be accurate enough for his purpose down to the one-thousandth of a grain.

It is merely a thin strip of pine wood, one foot long, and one-third of an inch wide. This serves for both beam and pans. A fine sewing-needle, thrust through its middle, from edge to edge, and projecting on each side, furnishes the pivots on which it turns. These pivots rest upon the up-turned edges of a piece of sheet brass or tin, which is fastened with a tack, or small screw, to a board a little longer than the strip; which board serves as the platform, or floor, of the instrument. The piece of tin is one inch long by half an inch wide. Its two ends are squarely turned up to the height of one-quarter of an inch; so that the strip, or beam, has a play of only half an inch or so. From the needle as a centre, ten equal divisions are marked off towards each end, and numbered with a pencil, 1, 2, 3, etc. Nine-sixteenths of an inch will be about right for each space. This will leave a little margin at each

end of the beam, and is moreover conveniently marked off; most pocket rules being divided into sixteenths of an inch. When completed, the beam is adjusted to an exact equipoise, by taking off little shavings from the under side of the heavy end, with a penknife.

Three weights are all that are necessary: one of *one* grain, one of *one-tenth* of a grain, and one of *one-hundredth* of a grain. The standard for the first may be found at any drug-store,—the grains being identical in troy and apothecaries' weight. It may be made of brass wire; and its ends so bent up as to offer a convenient grasping-point for a pair of small forceps, such as are used by watch-makers. To make the second, place the first upon the 1 mark on the beam,—that is, the division nearest the centre of the strip,—on one side; and balance it with a piece of fine wire, clipped to suit, upon the 10 mark of the other end. For the third weight, place the *second* upon the 1 mark, and balance it in like manner with a small pice of very fine *wire*,—or *broom-corn*,—or *thread*,—placed upon the 10 mark of the other arm. For the handling of these weights, the small forceps will be required.

To weigh a button, place it upon the 10 mark of one arm of the beam. If it weighs just one grain, it will, of course, be exactly balanced by the grain weight placed upon the 10 mark on the other arm. But if the grain weight is too heavy for it, move the said weight *back* towards the center, one division at a time, until it is found too light. Leaving it there, place weight No. 2 upon the 9 mark of the same size. If found too heavy, move that also back, until it is found, in *its* turn too light. Use weight No. 3 in the same manner.

The three weights now denote the weight of the button, in thousandths of a grain. Thus, in the assay we are now making: suppose the grain weight at 9, the one-tenth grain weight at 6, and the one-hundredth grain weight at 3. The largest gives the first figure in *tenths* of a grain; viz.: 9. The next, in hundredths, gives .06; and the next, in thousandths, .003. The weight of the button, then, is .963 gr.=963 thousandths of a grain.

Now to apply the rule. If we multiply .963 by 121.5, the product is 117. (The fraction is here too small to be noticed.) There is, then, one hundred and seventeen ounces of metal in one ton of ore.

Duplicate grain weights may also be prepared for use in case the button should exceed one or more grains. The manner in which they are to be used will be obvious.

We now return to our assay. Having learned the amount of metal in a ton of ore, the next thing is to ascertain what that metal *is*. The button is, we will suppose, *white* in color. We know it to be either *silver*, or *an alloy of gold and silver;* for the baser metals have been removed by the cupellation. We proceed to boil it in nitric acid. It is first *flattened* into a thin ribbon with a bright, clean hammer, upon a smooth anvil. After being annealed in the flame of a spirit lamp, and cooled, it is coiled, by means of a small pair of pliers, into a loose *roll*. This little roll is termed a *cornet*. The object of the flattening, is the extension of the surface to be acted upon by the acid. We put this cornet into a matrass, or small glass flask; the bulb of which is perhaps one-third full of dilute nitric

acid.* We now heat it over the spirit lamp, slowly at first,—then allowing it to boil briskly until the red vapors cease. The acid is then poured off carefully, and the same quantity of *strong* acid,† which we have meanwhile been heating in another flask, is poured in. The boiling is now kept up for about ten minutes. By this time, the silver will all be dissolved, and the gold, if there is any, will remain either entire, in the shape of the cornet, or as brownish-black particles. A *third* boiling is sometimes performed.

The acid is again poured off, and the flask filled with hot distilled water, for the purpose of washing its contents. This is also poured off; care being taken, at every pouring off, to avoid losing any particles of the gold, which may have crumbled. The flask is again filled with hot distilled water,—this time completely,—and a little clay crucible, called a "dry-cup," inverted over it. The two together are then, by a quick movement, reversed. The gold falls slowly down into the cup, and the matrass is then carefully raised until its edge is on a level with that of the cup, when it is "slid off" on one side. The water is now poured out of the cup, which, with its contents, is thoroughly dried over the spirit lamp, and then kept at a red heat in the muffle until the gold assumes its proper color and lustre.

It is now weighed, in the manner before described. If it is crumbled, it may be wrapped in sheet lead, and cupelled into a little button for convenience in handling. Suppose our assay balance shows it to weigh 102-thousandths of a grain=.102 gr. The entire button of

*Specific gravity, 1.20. This is determined by a *meter*.
†Specific gravity, 1.30.

metal, it will be recollected, weighed .963. The difference is .861; which is, of course, the weight of the silver which we have dissolved by the treatment in nitric acid.

The ore then contains:

In gold,—.102×121.5=12.39 ozs.
In silver,—.861×121.5=104.61 ozs.

This is pure gold and silver of one thousand thousandths fine. And as gold of that quality is valued at $20.67 per oz., and silver $1.30 per oz., we find the assay value of the ore to be

12.39 ozs.×$20.67=$256.10—gold,
and 104.61 " × 1.30= 135.99—silver.

Total value per ton of 2,000 lbs. .=$392.09

The process which we have detailed is subject to modification according to circumstances. If, for instance, when we boiled the flattened button in acid, it had been *entirely* dissolved, we should, of course, know that it consisted wholly of silver. If, on the other hand, we had found that a considerable amount of gold remained, equal in weight to, say, one-third of the silver, we should have been obliged to make another separate assay of the ore *for gold*, in order to determine it with accuracy; for it has been found by experiment, that unless the proportion of the silver to the gold in an alloy is at least *three to one*, the acid will not penetrate the metal sufficiently to remove the silver. In such cases it is therefore necessary to *add* silver, in sufficient quantity to bring it up to that proportion. In an assay of gold bullion, it is usual to add, at the out-

set, three parts,* by weight, of pure silver† to the clipping which is to be tested; and the two are cupelled, together with about sixteen parts of pure lead, into a button, which is then treated with acid as above. This is called "*quartation.*" But, in a case like the one in hand, we cannot know, even approximately, the proportion of gold, until we have made a preliminary trial, such as we have detailed. If, indeed, the button had been of a deep yellow color, we might have "quartated" it, at once, with three times its weight of silver; if it had been *slightly yellowish*, with *twice* its weight. But it was *white.* We might have quartated it with, say, *its own* weight of silver; but it would have been simply an experiment.

In fact, this is really a preliminary assay, so far as the gold is concerned; though in our case it was complete—there having been silver enough in the button to "part" it with. But if, as we said above, we had found the proportion of gold large enough to make quartation necessary in order to determine it, we would proceed to make another assay *of the ore* for gold; cupelling the original crucible button with quartation silver, and then treating it, as before, with acid. The amount of gold, thus obtained, if subtracted from the whole amount of metal,—as obtained in the first assay, which was cupelled without any addition of silver,—will give the amount of silver. This would in fact be the most accurate way to proceed in *any* case—even the one above supposed,

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*The proportion more commonly used of late years is two and a half parts.

†The processes of preparing pure silver and lead will be given among "*Additional Notes,*" farther on.

in which the cupel button shows a deep yellow color; for it is proved by experiment, that if the ore contained *copper*, the button would lose gold, if cupelled without quartation silver; so that, in case *this* ore contained copper, *this* button would have lost gold, no silver having been added. Nevertheless, it would probably be sufficiently accurate for our purpose, to melt our globule, if of a yellow color, with three times its weight of pure silver, and then subject it, as before, to the parting process by acid. This can be conveniently done with the blowpipe on a piece of charcoal, if we have become familiar with the use of that instrument.

We have thus given an idea of the manner in which an assay is made. We will now make some additional notes upon points not touched upon in this description, but purposely omitted, in order that it might be made as simple and as brief as possible.

ADDITIONAL NOTES.—The ore to be tested, with the fluxes, etc., may be weighed either with the ordinary small scales which miners generally have, or with the larger scales used by druggists. The grain and the ounce are the same in troy as in apothecaries' weight.

The crucible should be thoroughly *annealed* before using, by being gradually raised to a red heat, and as gradually cooled. Care must be taken, that at the time of using, it be perfectly dry; else it will be likely to crack. It should be provided with a cover:—if it is not, a piece of an old crucible will answer.

The "Hessian," or "sand" crucibles, answer the purpose well, and are cheapest. French clay crucibles are very good. Black-lead, or plumbago, crucibles, are, comparatively speaking, rarely used in an assay.

The salt with which the assay is covered, fuses first, and prevents evaporation. Before being used, it should be "decrepitated,"—or deprived of its water, by heating in a covered iron vessel.

Borax-glass is made by melting ordinary borax of the shops in a crucible at a dark-red heat. It is then pulverized for use.

Litharge, as purchased, generally contains some silver. This would of course vitiate an assay made with it. To secure accuracy, two ounces may be previously melted in a crucible with fifteen grains of charcoal, and the button cupelled. The weight of the little silver globule which results, must be noted down, and subtracted from the weight of the cupelled button in every assay in which two ounces of the same lot of litharge is used.

Pure lead may be prepared by dissolving acetate of lead—(sugar of lead)—in hot water, filtering through paper, and precipitating with metallic zinc. After washing, the precipitated lead is dried, and melted with borax for use.

The purity of lead may be tested by cupellation. If it colors the cupel uniformly of a light yellow, and no globule of metal remains after the operation, it is sufficiently pure. A correcting test for lead, may be made like the one given above for litharge.

Pure silver is prepared by dissolving silver in nitric acid, and precipitating it as a chloride of silver by common salt. After the chloride has been thoroughly washed, by repeated rinsings with hot water, plates of iron are introduced, which take up the chlorine, leaving the metallic silver. This is then heated until it "cakes," so as to be easily handled.

Wheat flour is sometimes used instead of charcoal. In both cases, it is *carbon* which is furnished. The object is to take up the oxygen of the litharge,—which is an oxyde of lead,—and reduce it to metallic lead. *Twice* the quantity is necessary, if flour is used.

The carbonate of soda should be that which has partially lost its water of crystallization by exposure to the air.

The charcoal should be so replaced from time to time, as to keep all parts of the crucible equally hot.

The crucible should be withdrawn from the fire as soon as its contents are perfectly liquid. Otherwise, any litharge which remains unreduced to lead, might act so strongly upon the crucible as to "eat" through it.

For handling the *crucible*, ordinary blacksmith's tongs will serve. For handling the *cupel*, a pair of tongs may be extemporized with a piece of narrow hoop-iron, bent like sugar-tongs, with the ends slightly curved so as to fit around the cupel, grasping it in such a manner that it is safe against being either dropped or crushed. A wire hook is often useful for changing the position of the cupel.

The "driving" at a lower temperature, and the judicious raising this to a higher, is of the utmost importance. There is an old German rhyme which has been translated thus:

> "Cool to drive and hotter 'blick'*
> Is of assaying the master trick."

It is only to be learned by practice. The cupel must of course be closely watched. A piece of window glass

* "*Blicking*" is "*brightening.*"

can be so held as to protect the eyes from the heat while examining it.

The nitric acid used for parting, must be *pure*. If adulterated,—as is sometimes the case,—with muriatic acid, it is unfit for use; a mixture of these two acids dissolves some of the gold, and of course vitiates the assay. It may be tested with nitrate of silver,—(lunar caustic). If that cause *cloudiness*, it will not answer. The milky cloud consists of chloride of silver; and shows the presence of muriatic (hydrochloric) acid.

The acid sometimes boils unsteadily, and with such turbulence as to be thrown out of the matrass, carrying the gold with it. The introduction of small round pieces of porous earthen-ware will prevent this; bits of a broken dry-cup may be used.

In flattening the button, it should be turned edgewise occasionally, and the edge kept even, with light blows; so as to make as *uniform* a ribbon as possible. It is less likely to crumble, and therefore more easily managed; besides giving a more correct result. It should be annealed and cooled, from time to time, during the hammering. It is generally *rolled* out, after the first two or three blows with the hammer.

If silver largely predominates in the globule, it is often submitted to the acid boiling without flattening; and is moreover boiled only *once*, and that with strong acid. The relative proportions of gold and silver in a small globule may be determined *approximately*, by simply putting it into nitric acid, and heating it. If it contains one-fourth gold, or less, it turns black, and the silver is slowly dissolved; leaving the gold as a powder, or a spongy mass. If it is *more* than one-fourth

gold, the silver is *not* dissolved, although the globule turns black, as before. If it is *one-half* gold, no change takes place in it. If there is a large proportion of gold, the color of the globule will show it.

In the assay of *bullion*, *two* tests are generally made at the same time, as correctors of each other. If they are not identical, the assay is rejected, and the operation repeated with new clippings. The bar may not be homogeneous; in which case it must be re-cast.

FLUXES AND SLAGS.—In the study of ore-assays, the subject of *fluxes* is of the greatest importance. The main point is to produce a fusible slag, which will absorb all the metals which we do not want. In the *fusion*, or *crucible* assay of gold and silver ores, especially those containing sulphurets, *litharge* performs a principal part. It forms with silex such a slag as we have described; and indeed melts easily with most minerals. Gold and silver unite readily with melted lead;—and can be collected by bringing them in contact with it. The first thing in a gold or silver ore assay, is to make an alloy of these metals with lead; and the next thing is to get rid of the lead by oxydation in a cupel. The first is generally accomplished by melting the ore with a proper proportion of litharge, aided by other fluxes. The other base metals are oxydized, and dissolved in the slag;—provided we have used the proper fluxes.

The cupellation depends entirely upon the lead. An alloy of lead and gold, or one of lead and silver, or one of all these three together,—is easily cupelled. A moderate proportion of copper can be got rid of in this

way,—its oxyd being carried into the cupel with that of lead; but copper and gold alone cannot be cupelled. With, however, a large addition of *lead*, it can be done. With less lead, a loss of gold occurs; owing to its absorption together with the oxyd of copper. At best, copper cannot be wholly removed by cupellation.

The different sulphurets with which the precious metals are associated, require different proportions of fluxes to decompose them. Thus, while thirty parts, by weight, of litharge is required for the decomposition of *copper* pyrites, *iron* pyrites requires *fifty* parts. When fused in these proportions, both the ore and the litharge are decomposed; the oxygen of the litharge unites with the sulphur of the sulphuret, forming sulphurous acid, which goes off in the form of gas, while the metals remain behind, alloyed with the lead;—a part, however,—as, for instance, iron,—remaining as oxyds. A portion of the litharge acts as a *flux*, dissolving the earthy matters, etc., and forming a slag.

These are the proportions required if litharge is used *alone* with the sulphurets. It is easy to see that by this means an inconveniently large quantity of lead would be produced for cupellation. But a part of the oxydation of the sulphuret may be accomplished by the use of *nitre (saltpetre)*; thereby obviating the necessity for so large a quantity of litharge, and leaving, therefore, less lead to be cupelled. By this means, the amount of litharge necessary may even be reduced to *four* parts. A large crucible is necessary, for the nitre expands to such an extent when melting that it would otherwise overflow. On account of the danger of loss to the assay, from this cause, and some other objections, the use of nitre is not generally to be recommended.

The carbonates of Potassa and Soda, borax, and some other fluxes, are, however, extensively used. These substances form very fusible compounds with silex. Quartz may be made soluble in hot water, by melting it with four parts of potash. It is then a silicate of potash.

Metallic iron is also used as a flux. It is oxydized at the expense of the litharge which is used with it, and produces a fluid slag. *Black Flux* is much used. It is made by mixing two parts of cream tartar with one part of salt-petre, and throwing the mixture in small quantities, gradually added, into a crucible at a low, red heat. A mixture of carbonate of potassa with ten per cent. charcoal, is sometimes used instead of black flux. It is essentially the same. *Pounded glass* is also used as a flux.

A *mixture* of fluxes is more effectual than a single one. It may be said, in general terms, that the more fluxes used, the more fusible the slag.

We will now give several "recipes" for the preparing or "dressing" of assays; noting the particular class of cases for which each is suited.

For poor pyritiferous ores containing silver.

Pulverized ore..... 1 part
Litharge.....20 "
Borax glass..... $\frac{1}{5}$ "

This is suited to ore containing sulphuret of copper.

Pul. ore..... 1 part
Saltpetre..... 2 "
Litharge..... 2 "
Carbonate of soda..... 3 "

Cover with common salt.

Pul. ore	1 part
Carbonate of Potassa	2 "
Litharge	3 "

For richer ores.

Pul. ore	1 part
Litharge	6 "
Carbonate of potassa	4 "

(or, 2 parts each carb. sod. and carb. pot.)

Sulphate of Soda (anhydrous).. $\frac{1}{8}$ part.

Cover with common salt. This is heated at first gently, for 12 to 15 minutes, until action ceases in the fluid mass. The temperature being raised for 15 or 20 minutes to a low white heat, it is then withdrawn.

The following is in use in English smelting works, *for rich silver ores containing antimony and arsenic;*

Two ounces of pulverized ore and the same quantity of litharge are rubbed together in a mortar. The mixture is poured into a crucible; from one-half to one ounce of carbonate of soda is spread over it, and on the top 200 grains of small iron nails. These sink in the melting mass, are oxydized by the litharge, and produce a fluid slag.

For poor tailings from silver ore.

One part of pulverized ore and three parts black flux, are put in a clay crucible, the surface levelled, and covered uniformly with one part granulated lead.* The

*Granulated lead is prepared by pouring melted lead into a wooden box, which is rapidly shaken at the moment the lead is on the point of cooling. As it strikes the sides of the box, it falls *in grains*, which are then sifted for use; the larger grains being laid aside for re-melting.

whole is covered with a thick layer of common salt, (decrepitated.) With a gradually increasing heat it is smelted for one to two hours in the muffle furnace, or in the crucible furnace,—in the latter case, with a cover. If the ore is one which is not easily fused, from $\frac{1}{2}$ to 1 part of borax is added at the time of charging. The crucible should not be more than two-thirds full.

In Freiberg, the following is used for the same:

Ore.....	1 part
Black Flux.....	$1\frac{1}{2}$ "
Assay lead.....	$2\frac{1}{2}$ *a* 4 "

This is subjected to a three hours' heat in a wind furnace.

Six or eight crucibles are charged in this way, and the buttons *scorified** together into a single one, which is cupelled. At the same time, 6 or 8 ozs. of the same test lead must be concentrated and cupelled; and the amount of silver obtained subtracted from the assay. The button shows, of course, the amount of metal in the total quantity of ore used.

The above is for cases in which the earthy matters predominate. When the tailings or ore contain sulphurets, litharge is used instead of lead, and no coal added. Instead of black flux, a mixture of carbonate of potassa and powdered charcoal may be used.

For poor galena containing silver.

Pul. ore.....	1 part
Black Flux.....	$1\frac{1}{2}$ "
Iron filings.....	$1\frac{1}{10}$ "
Carbonate of Soda.....	5 "

*Scorification is described in another page.

Or, instead of the black flux and iron filings, 7½ parts of litharge and ½ part saltpetre may be used. Another recipe gives 1 part carbonate of soda and ⅓ part nitre.

For Auriferous Pyrites.

Pulverized and roasted ore..... 1 oz.
Litharge.. ..... 1 "
Dry carbonate of soda..... ½ "
Dry and finely powdered charcoal 15 grains.

This is put into an earthen crucible of such size that it is only two-thirds filled, covered with a layer of powdered borax-glass, and melted. As soon as the slag is perfectly liquid and homogeneous, it is withdrawn from the fire; lest the unreduced litharge should cut through the crucible.

The same recipe may be used for ore which does not contain sulphur; in which case it is not necessary that it should be roasted.

Instead of litharge, red lead may be used, or, if neither are to be had, dry white lead will answer the purpose.

For unroasted ores containing gold.

Pul. ore..... ..... 1 part
Carbonate of potassa..... 4 "
Litharge..... 8 to 12 part
Glass and Borax..... ¼ part
Coal dust..... 1/6 "

Cover with salt. Sugar of lead is even better than litharge.

For very poor pyritiferous ores containing gold.

A *pound* of the pulverized ore is thoroughly roasted over the fire, in an iron pan which has been rubbed over with chalk or clay. It is then mixed with ¼ lb. carbonate of potassa, ¼ lb. black flux, and 1 lb. granulated lead (or litharge,) covered with salt, and smelted for two hours. This may be done in a single crucible, or the charge may be distributed among several small ones. It is then scorified until a single button is obtained for cupellation. If the ore is *very* poor, as much as three pounds must be used for the assay.

In all these crucible fusions, it is essential that all sulphur compounds be decomposed,—and that the mass should become perfectly fluid; otherwise more or less gold is retained.

For Iron Pyrites.

Pul. ore	1	part
Litharge	4 to 8	"
Carb. pot. (or sod.)	2	"
Charcoal dust	1/16	"
Calcined borax	½	"

Cover with salt. Melt at a moderate heat, and at the close raise to a white heat for 15 minutes.

Overman gives a process of his own invention for the assay of gold bearing sulphurets, which he considers more correct and perfect than any other. It is as follows:

The pounded ore is intimately mixed with 10 or 15 per cent. of litharge—(unless it contains galena, or lead in some form or other, in which case none is used,)—

and to the mixture is added one-half its weight of common salt. It is then moistened, to dissolve the salt, and evaporated to dryness, while being constantly stirred. It is then gently heated in an iron pot with a concave bottom. As soon as it shows signs of melting, it is diligently stirred with an iron rod; and when it is semi-fluid, some small pieces of burning charcoal are stirred in, to reduce the litharge to metallic lead. The heat must be so regulated, that the lead remains suspended, and does not sink to the bottom. By constant stirring for half an hour, this lead is brought in contact with all the particles of gold. The whole mass is then quickly thrown into cold water. The slag dissolves, and a fine black powder remains in the vessel, which consists of the sulphurets of various metals, and metallic lead. Water is added to gently wash away the sulphurets, and the lead cupelled.

By this process an alkaline slag is avoided. This he considers important, inasmuch as any oxyd or sulphuret of gold which might be present, is soluble in an alkali.

We may sum up the matter thus: we wish to have all the sulphurets decomposed by oxydation, while at the same time we wish to have as little as possible of the litharge reduced to metallic lead to be cupelled; hence the addition of other oxydizing agents, such as saltpetre, &c. On the other hand, if the ore does not contain sulphur or something else, to take up the oxygen, there will not be sufficient litharge reduced to furnish the necessary quantity of lead; we then add *carbon* in some form, as charcoal, wheat flour, or black flux.

The amount of the different fluxes to be used, then, is determined by the character of the ore; and as we can-

not know that precisely beforehand, it is advised to make a *preliminary* assay, in the following manner. Mix intimately 20 grains of the powdered ore with 500 grains of litharge. Heat gently at first, then quickly raise to red heat until fusion is complete. Cool the crucible, break it, and weigh the button. If but little of the litharge has been reduced to metallic lead,—say one-half the weight of the ore taken,—*charcoal* would be used with the litharge in the assay. If the button is, say, double the weight of the ore, then *nitre* would be used. If, again, the button should be found to weigh about the same as the amount of ore taken, the litharge would be used without either of these.

It will be perceived, that for poor ores, a much larger quantity than we have heretofore contemplated, must be taken as the assay sample, in order to obtain an appreciable button. It may be necessary to use *pounds*. If we take a troy pound as the test, and the button obtained weighs one grain, the amount, in grains, of metal in a ton of the ore, is equal to the number of troy pounds in a ton avoirdupois. This is 2430+; but it will be sufficiently near to call it 2400. This number of grains is exactly 5 troy ounces. We may then give the following *rule* for cases

Where a troy pound is the assay sample:

RULE.—Multiply the weight of the button, in grains and decimals of a grain, by 5. The product is the amount, in troy ounces and decimals of an ounce, of metal in a ton of 2000 avoirdupois pounds.

If *two* pounds, weight is taken as the sample, the multiplier will be 2.50; if 4 lbs., 1.25; &c.

Scorification.—We now come to a mode of assay which is pronounced by all authorities to be the simplest, quickest and most correct of all; viz: the assay by metallic lead, or *scorification.* It is applicable to all cases of assay, for either gold or silver. It consists in melting the ore with metallic lead, under such conditions as to form with it a fusible slag in connection with the oxyd of lead, or litharge, then and there produced; and at the same time to bring the melted lead in contact with the metal of the ore, forming an alloy. It is thus performed:

One-eighth of an ounce,—60 grains,—of the pulverized ore is thoroughly mixed with half an ounce of granulated lead. The mixture is put into a *scorifier*, or shallow dish made of close-grained fire-clay, and covered evenly with another half-ounce of granulated lead. If the ore contains much earthy matter, ten grains or so of borax is added, to render it more fusible; but if the assay will work without, so much the better. It may if necessary, be added afterwards. With much sulphur present, borax is to be avoided; for it causes the slag to form too rapidly in the beginning.

It is now placed in the muffle, already at a bright-red heat, and the opening closed by pieces of charcoal. At the end of fifteen or twenty minutes, the melted metal in the centre is found to be surrounded with a fluid slag, from which thick lead fumes are rising. The muffle is now opened, the draft closed, and in the current of air which passes over the vessel, the slagging goes on for perhaps fifteen minutes more;—the temperature being regulated by the addition of coal at the mouth of the muffle, to raise,—or its withdrawal to lower,—the heat. The guide, in this respect, is the

position of the lead vapor; which, as in cupellation, ought to form a cloud suspended half-way between the roof and the floor of the muffle.

The slag by this time completely covers the whole surface. A short strong heat of about five or ten minutes is now given, until the slag is perfectly fluid. This point is ascertained by dipping a heated iron rod in it; if the slag runs off perfectly, on its withdrawal, the operation is complete. The assay is then poured into a basin-shaped iron or copper mould, which has been previously warmed and rubbed with chalk, or with fat, to prevent the button from sticking. When cool, the slag is separated by a blow with the hammer, and the button is ready for cupellation. If the operation has been properly performed, the button is quite malleable; if it is not so, the assay is not reliable.

Although this proportion of lead to the ore,—eight to one,—is generally sufficient, it is not always so. It depends upon the character of the ore. If that contains much zinc blende or pyrites, double this proportion is used; with copper or tin, twenty to thirty parts of lead to one of ore will be required. In general, the more sulphur in the ore, the more lead is necessary.

For rich gold ores, or those of medium value, this process is recommended as very exact. It may be repeated eight or ten times, and the resulting buttons concentrated into a single one for cupellation.

The only objection to the method of assay by scorification, is the large quantity of lead which must be cupelled. On this account, the crucible assays with litharge, which we have given, will often be found more convenient; while they are at the same time in general sufficiently accurate for all ordinary purposes.

ASSAY OF LEAD.

Galena, or sulphuret of lead, is assayed in the following manner:

One part finely pulverized ore is mixed with three or four times its weight of carbonate of potassa, in a clay crucible, and covered with a layer, one-fourth of an inch thick, of common salt, which has been decrepitated. It is then placed in the highly heated muffle, the mouth of which is closed with burning coals. When the assay is in perfect fusion, say twenty or thirty minutes, the temperature is reduced so that the crucible is of a brownish-red color; at which it is allowed to remain for some ten minutes. It is then again raised to the first temperature for ten or fifteen minutes. Poor ores,—or those which contain a considerable portion of iron or copper sulphurets,—are allowed to remain some ten minutes longer. The crucible is allowed to cool gradually; it is then broken, and the button weighed. If the assay is a successful one, the button will be soft, and of a bluish color. Black flux is sometimes used instead of carbonate of potassa.

Another plan, is to use three parts black flux to one of ore, and one-third part of iron wire in pieces;—with one-half part of borax on the top, if the ore contains much quartz. If it contains pyrites, it may be previously roasted. Nitre is sometimes added to the covering of salt, to aid the fusion. This plan yields a higher percentage of lead than that by carbonate of potassa.

Another which is recommended, is to fuse one part of galena with one part saltpetre, two parts argol,—(or

crude tartar)—a little carbonate of soda, and one-fifth part iron filings, with a covering of common salt, in a copper crucible. If this is well performed, it is claimed that the loss of lead will not be more than from five to ten per cent.

Four parts of a flux composed of equal quantities of the carbonate of soda and of potassa, with one-fifth part very fine iron filings, are also used to one part of ore. The melting may be performed in a flat dish in the muffle, or in a Hessian crucible.

All these methods give the amount of lead at too low a figure; on account of the volatility of the metal, and other causes.

ASSAY OF ZINC.

Zinc Blende.—An accurate quantitative assay of this ore is a difficult matter. The best way is to make what is termed an "assay of difference."

The ore is repeatedly roasted and pulverized, until the sulphur is all expelled. It is then mixed with one-fourth part, by weight, of finely pulverized charcoal, and heated in a covered Hessian crucible. The heat at first, and for some time, is moderate; it is then suddenly raised to a white heat, so as to form and evaporate metallic zinc quickly. The matter which remains is roasted in the muffle to remove all carbon, and then weighed. The difference between the weight and that of the ore at starting, is the weight of the oxyd of zinc which has passed off. The amount of metal is deter-

mined from this; 100 parts of oxyd being equal to 80 parts of metal.

This assay is never exactly correct; as other metals, if present in certain proportions, would also be evaporated at the same time.

The *presence* of zinc may be determined by the blowpipe, as shown in the chapter at the end of the book.

ASSAY OF COPPER.

Copper Pyrites, the most abundant of the ores of copper, is a sulphuret of that metal, in connection with a sulphuret of iron.

The first step in an assay of it is the *roasting*, for the purpose of driving off the arsenic, sulphur, and other volatile matter. Half an ounce of the powdered ore is placed upon a shallow dish which has been rubbed over with red chalk, to prevent sticking. It is covered with another dish, and introduced into the muffle. The heat is gradually raised to redness. The cover is then removed, and the ore diligently stirred with a hook of iron wire. As it becomes darker in color, the heat is raised still higher. When it is brown-red, it is *cooled* by drawing the dish to the mouth of the muffle. This operation, of alternate heating and cooling, is repeated until all smell of sulphur ceases: the dish is then taken out and cooled. A small piece of tallow is now added, and it is returned to the muffle. After the tallow is burned off, the temperature is raised to a white heat, and the operation is completed. The time required for the roasting, is from one and a half to two hours.

Two ounces of crude flux is now added, and thoroughly mixed with the ore. This flux consists of one part saltpetre to two parts of argol, or crude tartar;—the same with the black flux, except that it is not *deflagrated.* The mixture of ore and flux may be divided into two parts for convenience' sake, and put into two clay or copper crucibles, each with a layer of dry fine salt, three-fourths of an inch thick. It is now smelted in a small furnace. When perfectly fluid and quiet,—say after twenty minutes,—it is poured into a heated mould; and when cooled, the button of "crude copper" is separated from the cinder. It is black and brittle,—being a mixture of copper with other metals and carbon; and must be *refined.*

The refining is done by cupellation. A shallow cupel is made white-hot in the muffle. The button is pulverized, and if it contains lead,—which may be determined by the blow pipe,—is wrapped in a piece of paper and placed upon the cupel; if it contains no lead, it is wrapped in a piece of sheet lead of its own weight. When the copper begins to melt, half as much more lead is added. The assay is closely watched; and when the globule begins to show a *white* or *greenish-white* color, it is withdrawn at once, and a drop of water put upon it to prevent further loss by absorption into the cupel. Of this loss, there will unavoidably be more or less.

The process practiced at Swansea, Wales, is as follows:

An ounce of the ore is pulverized, and roasted in a flat dish, for two hours, with constant stirring. After being cooled, it is mixed with three-fourths of an ounce

of a flux composed of nitre, fluor spar, crude argol, borax-glass and common glass*—in a black lead crucible; and after being exposed to a heat gradually raised for one hour in an air furnace, is poured into a heated mould, which has been oiled. The button should be either of a copper-color, or *bluish;* otherwise it is rejected. By remelting with cream tartar and salt, it yields from one-half to two-thirds its weight in copper.

The *refining* is done thus:—A small crucible is heated to a white heat, and the warmed button dropped into it. Sufficient "refining flux"† to cover it, is added; then a layer of common salt. It is then melted in a closed furnace, and poured into a greased mould. When cold, the button is found to be fine copper.

All dry assays of copper give the actual percentage too low. It is absolutely necessary that the roasting be complete; and to secure this, the fluxes must be varied indefinitely, according to the ever-varying character of the ore. At best, it is tedious: and it is often only after repeated roastings, that the sulphur can be expelled. At Freiberg, copper pyrites is mixed with 15 per cent. of arsenic, 50 per cent. of borax, and 40 per cent. of glass. For the other ores of this metal, the proportions are varied for each respectively. Iron is often added, in the form of filings, to prevent the slagging of the copper. Only when the ore is such as to contain simply

*The recipe for preparing this flux is as follows: 1 oz. 3 dwts. nitre,—2 ozs. fluor spar,—1 ozs. 12 dwts. argol,—2 dwts. boraz-glass, and 3 dwts. common glass. These are finely powdered and thoroughly mixed; and are kept in a bottle with a ground glass stopper.

†This is made of 1½ lb nitre, 1 lb argol, and "a handful" of salt,—mixed and powdered; then heated in an iron pot and stirred with a red-hot iron. It is kept in well stopped bottles.

the sulphurets of copper and of iron, without earthy matter,—and is moreover tolerably rich in copper,—can a button be obtained which will give a test with accuracy; and in that case, even, the slag must be free from copper, and the button not only malleable, but,—both upon the surface and in its fracture,—pure copper-red in color. In this case, further refining is omitted.

Any gold or silver which may exist in the ore must be determined by a special assay; for there is nothing in the foregoing processes, which would give any indication of their presence.

Notwithstanding the defects of the dry assay, it affords results in a shorter time than the wet method; and these results are sufficiently accurate to serve as a guide for the working on a large scale.

ASSAY OF MERCURY.

Cinnabar, or sulphuret of mercury, which we have already mentioned as the chief ore of that metal, is assayed by distillation. The finely pulverized ore, mixed intimately with half its weight of iron filings, and a portion of black flux, is introduced into an iron retort of such size as to be only one-half filled by the mixture, and heated gradually to redness in a furnace. A blacksmith's forge will serve. The neck of the retort is wrapped at the end with a wide strip of cloth, reaching into a vessel of cold water, which serves as the receiver. The operation is complete when the mercury ceases to come over, and the metal is then weighed.

Carbonate of lime, or caustic lime with charcoal, are sometimes used instead of the black flux. It is well to add an extra layer of flux, one-fourth of an inch thick, to cover the mixture in the retort.

ASSAYS IN THE "WET WAY."

We have stated our preference for the dry assay, with the reasons for it. An imperfect test by it, is less likely to mislead than an imperfect test by the wet method. The latter consumes too much time, and requires too much study, for the practical man. Yet it gives more exact results,—especially in the assay of rich alloys: and is generally used in mints for bullion, —particularly in the determination of the percentage in the case of silver alloyed with copper. The "parting" of gold and silver, too, as we have performed it, belongs really to the wet method.

We shall devote a short chapter to it; giving an idea of the principles upon which are based the assay by it, of gold, silver, and copper.

GOLD ASSAY BY THE WET METHOD.

This is based upon the solubility of gold in nitro-muriatic acid. This acid,—or "*Aqua-Regia*,"—is a mixture of nitric and hydrochloric (muriatic) acids, in the proportion,—as generally used,—of one part of the former to four of the latter.

If the ore is rich, half an ounce of it, finely powdered, is digested in a small porcelain evaporating dish, upon a sand-bath, with three or four times its weight of aqua-regia. The gold is thereby dissolved. The solution is poured off, the dregs rinsed with aqua-regia,—which is

then diluted with water and added to the solution,—and the gold precipitated from it by different agents. As, however, it would be at once re-dissolved by the aqua-regia, the solution,—which is one of chloride of gold,—is *evaporated* before being precipitated. This expels the *nitric* acid; while *muriatic* is gradually *added*, as the evaporation is going on. The solution is then diluted with water, and is ready for the precipitant.

One of the best of these is the *sulphate of iron*, or *copperas*. This is dissolved in water, and added to the gold solution; both having been previously warmed. The chlorine leaves the gold for the iron, for which it has a greater affinity; and the gold falls, in the shape of a brown powder. This is filtered through paper, washed, heated to a low red heat, and weighed;—either in that form, or after having been cupelled into a button with a little lead.

Oxalic acid is also used as a precipitant. It is equally effective; but requires a longer time—from 24 to 48 hours—for its operation.

For poor pyrites, another process,—known as "Plattner's,"—is employed. A pound of the pulverized ore is thoroughly roasted in the muffle, or in an iron pan over the fire; the pan having been coated inside with clay, and dried. It is then dampened, and put into a glass vessel in the bottom of which is a layer of small pieces of quartz, covered with another layer of sand. Chlorine gas is now generated in a separate vessel, of lead, by heating a mixture of one part binoxide of manganese, four parts muriatic acid, and one part sulphuric acid. This gas is admitted at the bottom of the vessel,—passing, on its way, through a wash-bottle of water,—

and slowly permeates the mass of powdered ore. After some time, the greenish color of the gas is perceptible at the top of the ore; the operation is continued, however, for perhaps an hour longer. The gas is now shut off, and the chloride of gold, which is soluble, is washed out with hot water, into a suitable vessel. To this solution, muriatic acid is added; and the gold is then precipitated by means of sulphate of iron, in the same manner as in the first-described process of assay.

It is said that by this method the gold may be extracted even down to one ten-thousandth part.

SILVER ASSAY BY THE WET METHOD.

This is based upon the fact that silver may be precipitated from its nitric acid solution by a solution of common salt, or chloride of sodium. The process is as follows:

The pulverized ore is digested for some time, over a sand-bath, in nitric acid, and the silver thereby dissolved, producing nitrate of silver. A solution of salt, then added, throws down the *chloride of silver*, as a white powder. The precipitation is known to be complete, when further addition of the salt solution ceases to cause any milky turbidity. The precipitate is then filtered, through a small paper filter, which has been previously dried and weighed. It is now, with its contents, weighed again; and the weight, less its original weight, is the weight of the chloride of silver.

If the quantity operated upon is large, it may be precipitated in a stoppered bottle, and heated; then

thoroughly shaken, to condense the chloride, and poured into a crucible. Here it is repeatedly washed, with distilled water, and then carefully dried. The heat is raised sufficiently to cause it to cake together; in which state it is conveniently handled with tongs, and weighed.

But the most accurate method is that of Gay Lussac, now established, by law, in France. As it requires a special apparatus constructed for the purpose, and is not likely to be adopted by any of our readers, we will merely give an idea of the principle upon which it is based, without explaining the *modus operandi*.

If a definite weight of silver be dissolved in nitric acid, it will take a definite quantity of a salt solution of known strength to precipitate that silver as a chloride. That is to say;—*so much salt will throw down so much silver*. In this process, then, instead of weighing the precipitate, a salt solution of a certain strength is added to the solution of silver, until it ceases to throw down any further precipitate; and as, by the apparatus contrived for the purpose, the exact quantity used is noted, the exact amount of silver can be easily read off from the accompanying tables.

By this method, assays can be rapidly made, and with great exactness. It is necessary, however, for the operator to know *approximately*, beforehand, the percentage of silver. This he can learn,—if he is not already in a measure acquainted with the ore or alloy under examination,—by a preliminary assay, made in the ordinary way, either dry or wet.

The presence of *mercury* spoils this assay;—that metal, as well as silver, being precipitated by salt as an insoluble chloride. It is easily detected, however, and in such case the wet assay is rejected.

COPPER ASSAY BY THE WET METHOD.

The following seems to be considered the most reliable of the multifarious methods of performing the copper assay in the wet way: Half an ounce of the finely pulverized ore is warmed in a flask on the sand-bath, with a small quantity,—as little as possible,—of aqua-regia (composed of two parts hydrochloric and one part nitric acid),—until it is decomposed. It is then evaporated nearly to dryness, with a little sulphuric acid; afterwards moistened with hot water, and the washings added to the contents of the flask. Pieces of iron wire, about two inches long, and one-eighth of an inch thick, are put into it, and it is heated at near the boiling point, until a clean iron wire held in it will no longer be covered with a brownish coat. The flask is then filled with hot water. After a time, this is poured off, and the flask again filled in the same manner. A saucer is inverted upon it, and the two reversed; so that the iron wires, with the copper, etc., sink into the saucer. The flask is then removed by drawing it quickly over the edge of the saucer, and the copper rubbed off the wires with the fingers. It is washed two or three times with hot water,—which is set aside, and allowed to stand for some time, in order that any particles of copper that are suspended in it may be deposited. The metal has a pure copper-color. It is now dried at a moderate heat, and weighed.

This process cannot be used when there are present in the ore other metals which are also precipitated by iron; and must be modified accordingly.

The other wet assays of copper, called "colorimetric" assays, are based upon the fact that ammonia, added in excess, produces a deep-blue color with the solutions of the salts of copper; which color is more or less intense, according to the amount of copper in the solution. Therefore, by dissolving copper in nitric acid, precipitating it with caustic ammonia, and re-dissolving the copper in an excess of ammonia, standard solutions are prepared, which for a certain volume contain a definite quantity of copper. By comparing with these the color of the assay sample, treated in the same way, its richness is determined.

PART III.

HOW SULPHURETS ARE CONCENTRATED.

The process of separating the richer portions of the pulverized ore from the *gangue* and other matters which it is not desirable to work, is called *concentration.* It may be called a science in itself. The great number of different machines which have been planned and constructed for effecting it, is sufficient proof that it is not, in all cases, an easy thing to accomplish.

All apparatus for the purpose is essentially based upon the fact of the different specific gravities of the substances to be separated. It would seem then, at first glance, to be a simple affair; and so it *would* be, if all the particles under treatment were of precisely *the same size and shape.* But this is not the case. The infinite variety of size and shape complicates the problem infinitely. Particles of different *specific* weight, but the same *actual* weight, will, if of the same shape, go together. Thus it has been found by experiment, that a perfectly spherical piece of *quartz,* eight lines in diameter, will, in still water, fall through the same num-

ber of feet in a second, that a perfect sphere of *gold*, three-fourths of a line in diameter, will fall through. Here is the grand difficulty; the stumbling block in the way of success in the construction of a perfect concentrator. Volumes have been written upon the subject; and innumerable expedients suggested and adopted for meeting the requirement. We will briefly describe a few among these many devices. Most of them are,—or have been,—in use in European mines.

The "*Jigging sieve*" is an oak hoop, with a bottom of wire net-work, through which the water rises when the sieve is pressed into it, bringing with it the lighter portion of the contents, which are thrown off. There are also various *machines* on the same principle;—in which the sieve is moved up and down by means of cranks and eccentrics. None of these last do the work so perfectly as the first in the hands of a dexterous operator.

"*Petherick's Separator*" is an arrangement in which the sieves are *fixed*, while the water alternately rises and falls in them.

Edwards & Beacher's machine consists of a cistern of water, with a perforated screen a few inches below the top, upon which the pulverized ore is fed. Below this, in the side of the cistern, is a hole covered by a flexible disc of leather, which is moved by a connecting-rod and eccentric, causing the water to rise and fall through the screen. Scrapers moved in a similar manner back and forth upon the surface of the bed of ore, push off the upper and lighter stratum into a spout; while the heavier portion settles partly upon the screen, and partly at the bottom of the cistern.

In "*Richard's Slime Separator*," the slime is carried by a spout, upon a slowly revolving water-wheel, with buckets of a peculiar shape. The lighter particles of matter go off with the water in one trough, while the heavier settle at the bottom of the buckets, whence on their arrival at the underside, they are washed out into another trough by a jet of water which plays into the buckets.

In the "*sizing cistern*," the stuff is brought by a trough, and the current and pressure so arranged that the heavier portions descend and are conveyed away from a small opening at the bottom by a spout, while the lighter flow off over the top. These cisterns are of different kinds; some are square, others are funnel-shaped, or like an inverted pyramid.

Bourlase's machine consists of two inverted cones, one within another, with a space between, in which is an ascending current of water. The force of this current is so graduated, that while it allows the heaviest portions of the stuff to pass through it into a trough beneath, the lighter sands are forced upward, and flow over the top.

"*Wilkins' Separator*" is a cistern, into which the stuff is brought by a stream of water entering at the top on one side, and passing out at the top on the other side; carrying with it the lighter matters, while the heavier fall, and pass out at an aperture, just above which is a rising jet of clean water.

Another form of cistern is divided into several compartments; and the stuff falls into a *horizontal* current of water, instead of an *ascending* one. The heaviest matters settle in the first compartment, the next in the second, and so on.

The "*Strake*" belongs to another class of concentrating apparatus. In this class the separation is not accomplished by the subsidence of the ore in water; but the stuff being forced against a stream of water descending an inclined plane, deposits its heaviest matter first, while the lighter is carried off by the force of the stream. The stuff passes over a partition in a sluice-box, and is constantly "broomed" against the current by a boy, who stands below. The upper third of that part of the sluice below the boy, will contain the heavier matters, the next the "middlings," and the lower third the "tailings."

The "*Strip*" is essentially the same; but the shovel is used instead of the broom.

The *Lisburne* machine, for separating zinc blende from lead ores, has rakes or scrapers, which constantly plow the stuff against the flow of the stream.

The "*Flat Buddle*," used in Welsh mines, is a broad plane, slightly inclined, with a "catch-pit" at the bottom. A succession of these is used.

The "*Hand Buddle*" is essentially a sluice-box, in which a boy continually directs the current towards the upper end, with a light wooden rake.

The "*Round Buddle*,"—in general use in English mines,—is a fixed conical floor, eighteen feet in diameter, upon which the stuff is distributed from an annular trough, surrounding an upright slowly-revolving shaft at the centre. Arms are attached to this shaft, carrying brushes which traverse the floor. The stuff is deposited upon the floor in concentric rings; the one nearest the centre consisting of the heaviest matter, and so on to the outer one, which is made up of the lightest.

The "*German Rotating Buddle*" is a slightly conical, revolving table. The ore is introduced near the centre; and the heaviest falls at once in a ring around the said centre, and there stops. The remainder is deposited in rings according to density. Brushes, or rakes, moved by a crank, keep all the stuff which is below the first deposit in motion.

"*Concave Slime Buddle.*"—In this machine, the floor *descends* to the center, where a trough carries off the lighter stuff. The feed is at the center, into an annular trough, whence lead distributing troughs to the periphery. Arms, attached to the revolving shaft, carry strips of canvass, which sweep over the stuff upon the floor to keep the surface even. The matters are deposited in rings arranged in the reverse order to the one before described; the heaviest being, in this case, at the periphery.

Frames.—These are of different kinds. The "*Hand Frame,*" or rack, is a long inclined table, supported upon pivots at the ends, in such a manner that it can be tilted over to discharge its contents into receptacles beneath. The heaviest matter is found in the one under the upper end of the table; and so on down. The "*Machine Frame*" has above the table a trough of water, which is inverted at regular periods by the machinery, so as to wash off the ore into receptacles arranged as in the hand frame.

"*Percussion Table,*"—or "*Stossheerd.*"—This is an inclined table, suspended by two chains at the upper end, and two rods at the lower. Cams, on a revolving shaft, cause alternating movements of a horizontal wooden bar, that pushes against the upper end of the

table, giving it a swing forward. Being then released, it returns to its place, striking smartly against a block. The heaviest matter is found at the upper end.

The *Freiberg Shaking Table* is described as being fourteen feet long by six feet wide; and as hung by four chains, two at each end. Those at the lower end are five and a half feet long, and when the table is at rest, hang perpendicularly; those at the upper end, two feet long, with an inclination of from two to four inches.

The "*Sleeping Table*,"—used at Idria,—is a slanting chest, with holes in the bottom, which may be stopped, when desired, by wooden plugs. The lighter portions are carried out through the holes;—which are opened according to the character of the stuff treated.

"*Sweeping Tables*" are used in the Hartz. The water charged with the stuff is permitted to flow over an inclined table in successive currents, depositing the ore at a greater or less distance upon the table, while the sand flows off at the lower end. The matters upon the table are then swept together with a hand-broom, and through an aperture, now opened, into a tank below. The operation is repeated as often as the table is cleared.

In *Brunton's* machine, an endless canvass belt, stretched by two axles, one at each end, and supported by a third near the middle, rotates towards the stream of water bearing the ore. The canvass is inclined at an angle, and is stiffened in its width by strips of lath. The lighter portions of the stuff flow off at the lower end, while the heavier are carried over the upper axle, and deposited in a tank of water, through which the canvass passes.

The "*Dolly Tub*" is a wooden tub-shaped vessel containing the "dolly,"—an upright shaft, with arms or stirrers. The tub being partly filled with water, the crushed ore is shovelled in, until the mud is of a certain consistence. By means of a crank at the upper end of the shaft, two men set the dolly in motion. After a time, giving it a few more rapid final turns, they suddenly withdraw it. The tub is then struck repeatedly with a mallet, for the purpose of settling, or "packing" it. The stuff is found arranged in strata;—the heaviest at the bottom. An apparatus upon the same principle, driven by machinery, is also in use.

In "*Jordan's machine for continuous dressing*," the stuff is "sized" by a vertical revolving wheel, which is divided into compartments, by concentric partitions of wire gauze of different fineness; the coarsest being nearest the centre. As the wheel revolves, the contents of each compartment are discharged through the trough connected with that compartment, into a tube, with an ascending stream of water,—the force of which is so graduated as to be adapted to particles of that particular size;—and to allow only those of greatest *specific gravity* to descend to the bottom, while all other particles are carried up and discharged,—either to waste, or into a cistern for further treatment. One of these tubes with an ascending column of water, is attached to each trough. The valuable matter at the bottom of the tubes is drawn off as may be necessary.

"*Bradford's Separator*,"—an American invention,—consists of a table two feet ten inches long, and two feet two inches wide. The bottom is of copper gauze. It is suspended by vertical rods; and an alternating motion is given to it by cranks and connecting-bars.

The simplest form of concentrator in use on the Pacific coast, is the sluice, or inclined table, spread with woolen blankets. These blankets catch upon their rough surface the heavier particles of the stuff, which are from time to time rinsed off in a tank for future reduction. Most of the concentrating machines used here have apparently been suggested by some one or more of those which have been described. The reader will recognize the resemblance, under various modifications as to form.

We have intentionally omitted, up to this time, the mention of "*Borlase's Sludge-dressing Apparatus.*" We have left it to the last, because, first,—it seems to us to come nearer to the point than any other European machine for concentration has done,—and although imperfect, its inventor appears to have been on the right track;—and, second, because we wished, in connection with such mention, to give our own idea in reference to what we consider to be the true principle upon which such a machine should be designed.

It has been described as a "self-acting jigging machine." It is a horizontal pan, with a vertical axis. The feed is into an annular trough at the centre, surrounding the axis; and the stuff is led thence to the periphery of the pan, by stationary,—or sometimes revolving,—distributing troughs. The pan is kept in continual *oscillation*, by means of cranks and connecting-rods. The ore is deposited upon the level bottom of the pan, while the waste discharges itself at the centre, over a moveable ring, which rises mechanically as the ore accumulates. The waste is led off by a trough; and the ore is shovelled out as occasion demands.

The projector of this machine evidently had in view the two principles of *gravitation* and *centrifugal force*. He made use of these, it is true, to better advantage than most of his predecessors; but he failed entirely to see how easily the machine could be made to overcome the great difficulty which had been universally felt, in the fact that bodies of the same actual weight would accompany each other, however different in specific gravity. The larger particles of the waste were still found, as before, mixed with the smaller particles of the ore.

This machine evidently gave the hint for the "Prater Concentrator,"—which was a California production. But the patentee of *that* machine, also, failed to see its capabilities. The purchaser of the patent, however,—Mr. Hendy,—seems to have caught the idea, and to have acted upon it. We will first describe the machine as improved by him, and then give our reasons for this opinion.

The flat bottom of the pan has been changed to one, the section of which is a *curve*, of such form that the diminished centrifugal force at the centre is compensated for by the more abrupt descent at the start from that point towards the periphery. A descending channel secures the continuous approach of the heavier parts of the ore to *their* points of discharge at the periphery, and of any quicksilver and amalgam which may be present, to *their* point of discharge,—near the first, but underneath the edge of the pan. An adjustable gate regulates the discharge of the sulphurets, etc., at the will of the attendant. To the annular trough into which the feeding-spout discharges, is attached a hollow

arm with a T-shaped extremity pierced with holes. This is the *distributor*. By an ingenious contrivance, a rotary motion is given to this, and at the same time to a set of revolving *stirrers* below,—which by their rake-like teeth effectually prevent the "packing" of the sand. The entire upper margin of the pan is notched into a saw-like edge. Two pawls, attached to the end of the distributor, traverse this edge; and by means of these, each oscillation of the pan sends the distributor one notch forward in its circuit,—while its inertia causes the motion to be continuous.

But the point to which we wish especially to call attention, is this, viz.: that Mr. H., in making the machine *self-discharging*, has made it at the same time virtually *self-sizing*. A moment's examination will show this. If,—as he instructs,—the pan be kept "about half full of sulphurets,"—that is, if the discharge gate be kept closed until the periphery of the pan has had time to become completely filled with them,—and is then opened only just enough to *keep* them at that point,—*nothing but fine sulphurets can possibly be discharged*;—until, at least, the coarser particles of sulphurets out-numbered by accumulation, the finer ones,—when *they*, too, would begin to be discharged. The particles of lighter matters, *of whatever size they might be*, could never find their way to the outlet. The smaller light particles, of course, would not; and the larger light particles would be found just above the larger *heavy* particles, *at the top*. This may easily be proved by experiment: If, for example, we give a similar motion to a hand-pan filled with *shot*, or bullets, of different sizes, the shot will in time arrange them-

selves in the order of their sizes; *and the largest will invariably* be *found at the top.* If we take *playing-marbles,*—or other spheres of equal specific gravity, but different sizes, the result will be the same. If, again, we take a mixture of the two, the larger spheres of the lighter substance will be found above the larger spheres of the heavier, and so on down to the finest particles of each. The *size,*—as well as the *weight,*—determines the position which they will take. This is not due to gravity, but the reverse; it is the action of the *lever,*—the very force by which *we overcome gravity.* The radius of the sphere is the lever; and in proportion to the length of its radius, is the tendency of each sphere to surmount the one in contact with it. The force will be "*nil,*" if that one is of *exactly* the same radius with itself. Of course no other motion than an oscillating one will produce this effect. If the force were *simply centrifugal,*—that is, if the pan were *revolving,* instead of *oscillating,* the spheres would remain quiescent at the periphery;—the heaviest farthest from the centre. But as the pan is oscillated, each sphere tends to *roll* upon the top of its neighbor. The same principle holds in regard to particles of irregular shape;—lines drawn from the centre of gravity of a particle to its surface being its levers,—varying in length on different sides. The changes of position in the particles occur more readily in water than out of it; inasmuch as they are, in the former case, more free to move.

The following, then, are the movements which take place in this machine: The gate being closed, the pan is started, and the feed of pulp commences. Particles

of all kinds rush to the periphery of the pan. The lighter are gradually displaced by the heavier, of which latter the larger keep at the top. This is continued until a certain depth of the fine heavy particles has accumulated. The discharge gate is then opened to the proper extent, and a continuous flow of this fine heavy matter is the result. As the larger particles of the *heavier* matter accumulate, they will, after a time, outnumber the smaller, and will begin to find their way out with them; while the larger *light* particles will begin to crowd each other out at the centre, with the finer portion of the waste.

Here, then, we have the problem solved. Without the clumsy aid of sieves or other appliances,—the action of which is at best slow and imperfect,—the desired "sizing" is accomplished in the most natural, the surest, and most perfect manner,—by the operation of a law which is as unvarying as that of gravitation.

PART IV.

HOW SULPHURETS ARE WORKED.

In the *reduction* of sulphurets,—that is to say, the extraction, on the larger scale, of the metals which they bear, the same principles are involved as in the smaller operation of the assay; but the method of procedure is different. The fluxes and solvents used are *essentially* the same, but not identically; for in many cases the profitable working of ores would not admit of the use on the large scale, of substances, the cost of which for assay purposes, is trifling. Instead, for instance, of litharge, nitre, borax, carbonate of potassa, etc., as fluxes, we use lime, clay, salt, quartz sand, oxyd of iron, oxyd of manganese, and other substances which can be cheaply obtained in quantity.

As we have before said,—the study of fluxes and slags is of the utmost importance. It is, in fact, at the bottom of the whole subject of smelting. The material to be used depends entirely upon the character of the ore. The object is to produce a liquid slag of all the metals and other matters in the ore, except the one metal which we wish to obtain; which slag, being

specifically the lightest, rises to the surface of the melted mass, leaving the metal beneath. In order to attain this end, we add those materials which will render easily fusible the different foreign substances which we find, by assay, the ore contains; selecting those materials from among such as have a greater affinity for those foreign substances than for the metal to be produced. Fusibility, whether of metals or any other substance, is by no means dependent solely upon the degree of heat employed. Alloys melt more easily than single metals. Platinum, for instance, which is by itself infusible in any ordinary heat, is, in combination with lead, melted with comparative ease. Iron, which is very refractory when pure, if combined with arsenic and phosphorus, may be melted in a cast-iron kettle. Indeed, any metal may be made easily fusible by proper alloying. Slags, as was remarked in the chapter on assaying, become more fusible by multiplication. For instance, lime, clay, and quartz, melt very easily together; yet lime alone is very infusible,—and clay and quartz are by no means easily melted. Again: Quartz, or silex, melts easily with four parts of potash,—and the resulting silicate of potash is soluble in hot water. Slags are chiefly silicates; that is to say, combinations of silex with the oxyds of the metals contained in the ore.

These few general remarks will suffice to introduce the subject. They may serve to *hint* to the reader a broad field for study and experimentation.

REDUCTION OF GOLD-BEARING SULPHURETS.

These consist chiefly of iron and copper pyrites, often with galena. When "raw," they resist the simple treatment which serves for the "free" gold—viz.: that by amalgamation with quicksilver in the stamp-mill or the grinding-pan; and will yield their treasure completely, only after having been subjected to the process of "roasting,"—and thereby freed from sulphur, arsenic, and other substances inimical to amalgamation. Although in mechanical association with these substances, the gold seems not to be "freed" from them by the most thorough pulverization. Nor is there any very apparent advantage in the use of chemicals, in the pan or in the battery. Sodium-amalgam,—and, of late, cyanide of potassium,—have been tried; but although they seem to assist in some degree the amalgamation of *free* gold, by lessening the tendency to "*flouring*" in the quicksilver, they cannot, in the working of sulphuretted gold-bearing rock, take the place of roasting.

ROASTING.—For the performance of this, furnaces of various kinds are in use. Some of these consist of several stories, or shelves, so arranged, one above another, that the pulverized ore, introduced at the top, goes through a *series* of roastings at different temperatures, as it is transferred from each of these shelves to the next below. The heat is thus economized; for as the temperature required for the expulsion of that por-

tion of the sulphur which first escapes, is much less than is necessary for the expulsion of the remainder, this part of the process can be going on for a portion of the ore, at a greater distance from the fire-grate; and the heat, after doing its first work, be utilized a second, third, or fourth time. Others are so constructed as to revolve by machinery, thereby bringing every portion of the ore, in turn, in contact with the flame; thus doing away with the necessity of continually *raking* it back and forth.

But the simplest form of roasting furnace,—and the one in most general use,—is the *reverberatory*. Its construction is such, that the flame from the fire chamber,—which is at one end,—does not rise immediately towards the chimney; but after passing over a bridge, or fire-wall, is thrown back,—or "reverberated,"—by a low arch, directly upon the ore, spread out upon the floor, or "sole" of the furnace. This arch, which at its highest point is only some twenty inches above the floor, extends over the whole length of the furnace to a chimney of sufficient height to insure a strong draught. By this means, a large surface of ore is exposed to the heat and flame. A furnace with a capacity of one ton has a floor about twelve feet square,—or with that area.

The operation is as follows: The heated furnace is charged, through an iron funnel in the top or crown of the arch, with the pulverized ore. This is spread evenly over the floor, with an iron rake, introduced through holes made for the purpose in the side. Pulverized charcoal is sometimes added. Constant raking back and forth is necessary, while the roasting is going on; so that a fresh surface is always exposed. The

heat must not be sufficient to *melt* the ore so as to cause it to "cake" together. When the sulphur begins to burn, the heat in the fire-chamber must be lowered. As soon as the sulphurous smell ceases, the heat must be raised again to a light-red, instead of, as before, a dark-red heat; for,—as we have said,—the expulsion of the last portion of the sulphur requires a much greater heat than that of the first. The operation is completed in from six to twenty-four hours, according to the thoroughness of the roasting required.

The impediment to amalgamation having now been removed, the ore may be treated like ore containing free gold;—in amalgamating-pans, with mercury. This is a very simple operation, consisting essentially in the *brightening* of the gold by friction, and then adding quicksilver; which, when agitated with it in that state, eagerly seizes it. From the resulting amalgam, the quicksilver is expelled by "*retorting*;"—a process familiar to almost every worker of placer, as well as of vein mines.

But the process which is by far the most effectual in saving the gold, and the one now most in favor, is that by

CHLORINATION.—This is essentially the same with that described as "Plattner's," in the chapter on assaying. It is based upon the fact that gold forms, with chlorine gas, a chloride of gold, which is soluble in water. The *completely* roasted ore, when cool, is moistened to a wooly consistency, and put into a large wooden tank, made for the purpose. This tank is provided with a false bottom, raised a little above the true

one, and perforated with holes, over which some straw, or other loose matter, is strewed. Into the space between the two bottoms, chlorine gas is conducted through a leaden pipe, from the leaden generator. Salt is used instead of muriatic acid, in the preparation of the gas. The ore is spread evenly over the bottom of the tank, to the depth of a few inches at a time, as the greenish-yellow gas rises, until the tank is nearly full. The wooden top is then put on, and luted with flour paste; after which the continued charging with the gas is kept up for eight hours. Time is now allowed for the chlorine to dissolve the gold. After some ten or fifteen hours, the cover is taken off, and pure water let in. This "leaches" through the mass, and washes out the chloride of gold at the bottom discharge-hole, through a pipe, into a wooden vat. The admission of water is kept up until a solution of sulphate of iron will no longer produce a cloud in that drawn off at the bottom. The gold is then precipitated in the vat with a similar solution, and falls as a dark-brown powder. This is melted with borax into ingots for the market. These are of a high degree of fineness;—ranging from 992 to 996 thousandths.

This process will extract the gold more closely than any other. To perform it properly, however, requires experience with the particular class of ore under treatment; otherwise there are difficulties. Thus, for example: if the ore contains magnesium or lime,—a point which is determined by previous assay,—it is roasted with an addition of *salt*, in order that these may go into the tank as *chlorides;* as it is found that they will otherwise interfere with the operation to such extent as to be fatal to its success.

We have thus mentioned the reduction of gold-bearing sulphurets by amalgamation and by chlorination; in both cases after previous roasting. They may also be *smelted.* They may be mixed with quartz sand and fused with lead (or litharge, or galena),—and scrap-iron, in a reverberatory furnace. Or, mixed, as before, with silex, they may be melted with lime and oxyd of iron. When litharge is used, pulverized charcoal is added, to take up its oxygen and free the lead. The auriferous lead is then cupelled.

Iron pyrites is sometimes fused in a small cupola furnace with quartz containing free gold. The sulphuret and the free gold unite, and form a "matte," which settles below the slag made up of the earthy matters, silex, etc., with which the gold was associated. This matte is broken up, and roasted; and again melted, in the same way, with more of the ore. The process is repeated several times; until finally the rich resulting "matte" is fused with litharge and iron. The litharge is decomposed, leaving its lead to alloy itself with the gold; while the impurities are skimmed off from the surface. The alloy is then cupelled.

A process is mentioned by Phillips, for treating auriferous quartz,—which is as follows: The finely-powdered ore is melted with lime and oxyd of iron, producing, as slag, fusible silicates of lime and iron. Wrought-iron plates are introduced into the melted mass; and as soon as a thin film of gold has deposited itself upon their surfaces, they are withdrawn, and plunged into melted lead. By this, the gold is dissolved off. The process is repeated until all the gold is extracted; after which the lead is cupelled, and the gold thus obtained.

REDUCTION OF SILVER SULPHURETS.

Of the various methods by which the reduction of silver ores is effected, after pulverization,—which is always the first step,—the following will be described, viz.: 1*st. Pan-working of the ore, unroasted.* 2*d. Pan-working of the ore, roasted.* 3*d. Barrel Process.* 4*th. Patio Process.* 5*th. Smelting Process.*

PAN-WORKING OF THE UNROASTED ORE.—The Mexican *arastra* is the prototype of all the numerous pans which have been invented and brought before the public. They consist essentially of a circular iron basin with revolving mullers. They vary as to the shape of the bottom, the height of the rim, the form of the mullers, the extent of grinding surface, the motion given to the contents, working capacity, ease of management, and efficiency. The best pans will accomplish three or four times the work in one-third the time required by the arastra, or by the common pans. They receive a much larger charge, the motion of the mullers is much more rapid, and the pulp is more constantly brought between the grinding surfaces.

The pan is charged, while the muller is in motion, with the pulverized ore, and sufficient water to make with it a thin pulp. Quicksilver is then added, in quantity proportioned to the amount of ore and its richness. In general terms, we may give the quantity as about one-sixth the weight of the ore. The temperature of the pulp is regulated by the introduction of steam through a small pipe. The best result is obtained with

a moderate heat. All sorts of "chemicals," scientific and otherwise, have been employed, with a view to assist the amalgamation. Salt, sulphuric acid, the sulphates of iron and of copper, alum, peroxyd of manganese, and catechu,—are among these. Authorities differ in regard to their use. It would seem, that while some kinds of ore apparently give a better yield when so aided, others work better without anything at all; the *iron* of the pan itself, together with the friction to which they are subjected by the muller, serving to effect their decomposition. Mr. Kustel,—who was for some time manager of the Ophir Works, at Washoe, Nevada,—states that his experience in the working of Ophir ores was against the employment of chemicals. He says, however, that in the "common" pans, they do give a better result. The Ophir ores were worked in improved pans.

We give a few of the recipes which have been in use:

Sulphuric acid..... 3 parts.
Sulphate of copper..... 2 "
Common salt.....15 "

Sulphate of iron..... 1 part.
Sulphate of copper..... 8 "
Common salt.....80 "

Nitric acid..... 1 part.
Sulphate of iron ..... 1 "
Salt..... .....15 "

Sulphuric acid..... 2 parts.
Alum..... 2 "
Sulphate of copper..... $1\frac{1}{2}$ "

At the end of about three hours, the pulp is diluted by a stream of water, admitted while the machine is still running; and the three discharge holes are opened in succession, beginning with the upper one. The tailings from the two upper holes run into, and pass through, an "agitator," which is a large pan with revolving stirrers; while any quicksilver which may be carried out with them, settles to the bottom, and is saved. The quicksilver and amalgam from the lower hole are received in a suitable vessel. The amalgam is strained through a cloth, and retorted. The pan may be re-charged, however, without opening the lowest hole; and the operation repeated until the quicksilver becomes thick with metal.

This process is only suited for certain kinds of ore. The more sulphur, antimony and arsenic they contain, the less satisfactory the result; and the greater the necessity for a previous roasting. It is sometimes adopted where ore which is afterwards to be roasted for the barrel process, contains also gold.

PAN-WORKING OF ROASTED ORE.—The *roasting* will first be described. It is what is termed "chlorination roasting," or "chloridizing;" and is effected by the aid of common salt, or chloride of sodium. The furnace is similar to the one described as employed in the roasting of gold-bearing sulphurets. The process, too, is the same,—up to a certain point,—viz: the transformation of the *sulphurets* into *sulphates*, by the union of oxygen with the sulphur; this union producing sulphuric acid, a portion of which oxydizes the metal, and thus prepares it to combine with another portion, mak-

ing a sulphate. Common salt is then added, in proportion varying from six to twenty per cent.—according to the richness of the ore. This is sometimes done before the roasting is commenced; but the mass is in that case more likely to "cake." The peculiar action of the salt does not commence, even if it is mixed with the ore at the outset, until the sulphates are formed. The fact that this point is reached, may be known by the cessation of the sulphurous acid odor.

The heat is now increased; and "chlorination" commences. The sulphuric acid of the sulphates already formed first changes the sodium of the salt to soda, by oxydation, and then produces, with that oxyd, sulphate of soda; leaving the chlorine to combine with the metals, forming chlorides. These are chlorides of silver, and of whatever base metals may be associated with silver in the ore. Those of the base metals, such as copper, zinc, etc., may be decomposed by continued roasting, or by the use of carbonate of lime. It is, however, usual, unless the ore contains large quantities of base metals, to discontinue the roasting at an earlier period,—even before the complete chlorination of the silver,—permitting the sulphates to go into the pan *as such*. Being soluble in water, they are *there* changed into chlorides, which are decomposed by the iron of the pan itself, leaving the metals free to combine with the quicksilver. The amalgam will be of a low degree of fineness, owing to the admixture of base metals. The remainder of the operation is identical with the pan-working already described.

Barrel Process.—This is the Freiberg operation. It consists in amalgamating the *thoroughly* roasted and

chloridized ore in strong wooden casks, into which metallic iron is introduced to take up the chlorine of the chloride of silver, leaving the metallic silver free to unite with the mercury. These casks,—of which some twenty are carried by a single revolving shaft,—are about 2 feet 10 inches in length, and 2 feet 8 inches in diameter, with staves 3 or 4 inches thick. Half a ton of the ore, with, say, 35 gallons of water, and a hundred pounds of wrought iron in pieces, is the charge for each,—introduced through a door in the side of the cask. This door is then tightly closed, and the cask revolved,—at the rate of 15 turns per minute, for one hour and a half. By this time the chloride of silver has been transformed into metal. The consistency of the mixture should be that of a thick paste; and this is secured by adding ore or water as the case may be. Five hundred pounds of quicksilver is now added; and the cask revolved at the rate of 22 turns per minute for 18 hours. It is then stopped, filled with water, revolved slowly for two hours more, and discharged:—the quicksilver first, through a screw-plug hole into a suitable vessel, and next, the tailings through the opened feed-hole into a trough beneath, which conveys them into an agitator and settler. The quicksilver is strained, and the amalgam is ready to be retorted as in the cases already described.

The roasting for this process must be *complete;* and the base chlorides decomposed, as far as possible, in the furnace. If allowed to go into the barrel, they consume a considerable quantity of iron, and tend to cause the quicksilver to "flour," from the too great heat induced by chemical action;—besides reducing the fineness of the metal, as in the pan-working.

PATIO PROCESS.—This is the primitive Mexican method. It has been practised to some extent in the Washoe mines. It consists in spreading the pulverized ore over the stone floor of a yard, or "patio," in the open air,—chloridizing its silver with salt,—"reviving" it by means of roasted copper pyrites,—and collecting it with quicksilver.

The process is as follows: A considerable quantity of the ore,—say sixty tons,—having been finely ground in arastras, or by other means, is mixed with water to a paste, and spread over the floor of the yard to the depth of about one foot. Three per cent. of common salt,—or more, according to the richness of the ore,—is spread over it, and well mixed with shovels, and by treading with mules or oxen. It is then left at rest for a day or two, until the salt is dissolved. "*Magistral*,"—or calcined copper pyrites,—is now added, to the amount of about twenty-five pounds to the ton of ore; and mixed in the same manner as before. After the treading has been continued until the mass is of uniform consistence, quicksilver is sprinkled over the whole surface, in a shower, by straining through a cloth. The quantity used is three times the estimated amount of silver in the ore, as ascertained by assay. The tramping and turning over are now renewed, and continued for a portion of each day. When a test of the amalgam,—made by washing,—shows that the quicksilver is all taken up, a second portion of it is added,—equal to about one-half of the first charge; and afterwards a third, equal in quantity to the second. The mass is now carefully examined morning and evening; the treading being renewed every other day, until the

amalgamation is complete. This may occupy a month or more. The mass is then transferred to a large stone vat, through which a stream of water is constantly running. A revolving shaft, with arms, keeps the pulp in constant agitation;—and the amalgam sinks to the bottom, while the mud and lighter matters are carried off. The straining and retorting of the amalgam now complete the operation.

The chemical changes which are constantly going on in the mass, causes a rise of temperature. The experienced amalgamator watches this effect closely; and regulates it by the addition of lime, or of more "magistral," as the mass may become too hot or too cold.

Sulphate of copper,—(blue vitriol),—is sometimes used in default of the pyrites wherewith to make "magistral."

Some ores cannot be properly treated in this manner without roasting. Such are those containing copper, zinc and antimony.

All the processes which we have heretofore described involve the necessity of *retorting*, to separate the metal from the quicksilver. A few words may be said in reference to that operation.

RETORTS are of various shapes; oval, spherical, or cylindrical. The latter are those most used for the large operation. Such an apparatus consists of a cast-iron cylinder,—say four feet long,—capable of receiving a charge of eight or nine hundred pounds of amalgam. A pipe, also of cast-iron, leads from the rear end to a vessel of cold water, in which the quicksilver is condensed. This pipe terminates in a funnel-shaped

expansion, just above the water; but a cloth which is wrapped around the expansion, reaches *below* that surface. The condensing pipe is surrounded with a larger one of sheet-iron, which is kept filled with cold water by a constantly-running stream. The cylinder is set in a furnace of brick-work. After the retort is charged, the door is tightly closed, and luted,—and the fire started. The heat is never raised above dark-red. The operation lasts some eight hours; and is completed when the quicksilver ceases to come over. After cooling, the retort is opened, and the spongy mass of metal broken up for convenience in melting into bars.

SMELTING PROCESS.—This consists in bringing the silver in the ore into the state of an alloy with lead; after which the two are separated. Either metallic lead,—granulated, as we have already described,—litharge, or galena, may be used. The pulverized ore is roasted in a reverberatory furnace at a low heat, with constant stirring, until the sulphurous odors cease. The object of this roasting before smelting, is the expulsion of sulphur. By this means, a large portion of the metallic iron, which would be necessary to take up the sulphur in the furnace, is saved.

After the roasting, the ore is mixed with about four-fifths its weight of granulated lead, and one-fifth its weight of soda-ash.* About eight per cent. of metallic iron, and three per cent. of lime, are added. Instead of the lead, galena to the amount of twice the weight of ore may be used; in which case it should be mixed

*An impure carbonate of soda.

with the ore at the outset, and pulverized and roasted with it. The heat must not be sufficient to melt any portion of the lead. The fluxes to be used, vary with the character of the ore.

The mixture is now ready for the smelting. A blast furnace is generally used for this purpose. If an air furnace, the chimney should be of ample height to secure a sufficient draught,—say forty or fifty feet. Mr. Kustel describes a draught-furnace planned and built by him in San Francisco, for the purpose of smelting the rich ore from the Ophir mine. The design is derived from the Mexican cupel furnace. A cast-iron pan, thirty-seven inches in diameter and fifteen inches deep, filled with pulverized fire-brick slightly moistened and well rammed down, forms the bottom of the furnace. In this is scooped out, and smoothly finished, a basin-like cavity, thirty inches in diameter, which constitutes the crucible. This has a tap-hole at the bottom, for drawing off the metal, and a slag-channel at the brim, for removing the slag. The roof is an arch of fire-brick. The mixture of ore and flux is introduced in charges at a small door in the flue, some four feet from the crucible. The flue-plate, upon which it is placed, has an inclination of thirty degrees towards the crucible, and is covered in like manner with fire-proof material. The height from the bottom of the crucible to the arched roof is twenty-eight inches. The furnace being white-hot at the time the charging is commenced, the ore soon begins to melt, and to run into the crucible. The charge is renewed as room is made for it; the slag and metal in the crucible being frequently stirred together, with an iron rod introduced

through a door designed for the purpose. This goes on until the crucible is nearly full. The heat is now slightly raised for fifteen minutes; after which the slag is withdrawn through the channel, and the feeding renewed. This is repeated several times; until it is found that the "matte,"—or layer of impurities between the slag and the melted lead,—is within three inches of the slag-channel. The slag is now completely drawn off, and the matte and lead discharged through the tap-hole into an open hearth outside of the furnace. The matte is taken off with a fork, and the lead is ladled into warm iron moulds, which give bars of about twenty-five pounds each, ready for cupellation. The matte, which is more or less rich in silver, is pulverized with the next batch of ore; and while its silver is thereby saved, it serves as a flux. The slag also is preserved for the same purpose; as it generally contains a portion of matte.

The next process is that of cupellation;—by which the lead and silver are separated.

CUPELLATION,—on the large scale,—resembles rather the "scorification" process, than cupellation as described by us in the chapter on assaying. The litharge, or oxyd of lead, as formed, is not *absorbed*, but *driven off* by a blast. The furnace used, has, like the crucible furnace which has been described, a cast-iron pan, into which the substance of the hearth is solidly beaten. This substance is either bone-ash,—or a mixture of that substance with wood-ashes,—or marl,—or clay with limestone. The cupel is prepared in a somewhat similar manner as the crucible of the furnace

already described. A cast-iron ring, of the same size as the cupel, and six inches in height, is used to shape the upper part. The pan is eleven inches deep, and about four feet in diameter. It is perforated with half-inch holes, to allow the escape of moisture when the prepared hearth or cupel is dried; which must be done *gradually* and *perfectly*. A bellows, the nozzle of which enters at the back of the furnace, just at the brim of the cupel, and at a slight angle to the surface of its contents, keeps up a constant and regular stream of air upon the surface of the melted metal; thereby both furnishing oxygen to oxydize the lead to litharge, and at the same time driving off the litharge as fast as formed.

The German cupelling furnace has a *fixed hearth* and a *movable top*, called the "coppel," or hood. This coppel is a net-work of iron bars, riveted together; and has hook-like projections on the under side, to hold the clay which constitutes the lining,—two inches thick. The hearth is of marl. The coppel is lifted to and from its place by a swinging crane. The English furnace differs from this, in having a *movable hearth* and *fixed top*. The hearth, or "test," is made outside, and introduced into the furnace from beneath. It is generally made of bone-ash; and is shaped by an oval iron ring, with a bottom of cross-bars to give it strength.

The furnace being at a light-red heat, a piece of lead is introduced, and the effect noted. If the temperature is as it should be,—which is ascertained by the effect upon this piece,—the bars of rich lead, which we have spoken of, are added,—two at a time,—as fast as the melting goes on, until the cupel is full. The heat is

then raised for a time. The "scrapings," or light slag,—called "froth,"—are drawn off over the "litharge bridge" at one side, by a small canal scraped in the bridge with an iron bar, having a chisel-like end. The froth is soon changed to litharge; the flow of which is kept up throughout the entire operation. As soon as the channel for its flow becomes too deep, it is filled up with clay; and another is opened alongside. This is continued until the whole space allotted for the canals has been so appropriated,—say twelve hours or more;—the first one is then re-opened, but to a greater depth than before. The charging of bars is continued for two days. As the silver becomes richer, the heat must be increased, until the "brightening,"—which was described under the head of assaying,—takes place. The silver is either ladled out into hot iron moulds, or, after partial cooling, is lifted out through the fire-place in a single cake;—a pointed iron bar, placed underneath its edge, being used to raise it, with care to avoid bruising the cupel surface. A new litharge bridge having then been made with some of the same material, and thoroughly dried, the operation may be repeated; and so on until the supply of lead bars is exhausted.

Different silver ores require different treatment in smelting. What we have already said on the subject of fluxes and slags, will make this apparent. Some rich ores are melted, without previous roasting, in vertical blast furnaces, with lime, iron and lead ore; the mixture being introduced at the top, alternately with charcoal, and the metal drawn off at the bottom. Some are sufficiently rich to be profitably reduced in large crucibles with litharge, in an ordinary draught furnace.

Silver sulphurets with iron pyrites, can be "melted for matte" in a blast furnace; and the matte either amalgamated, or melted again with lead. *Copper* ores containing silver, can be melted for matte in the same way, and then again with lead into *cakes*, which are treated by the "liquation" or "sweating" process, as it is termed. This consists in heating the cakes of copper, silver and lead, up to a point sufficient to melt the silver and lead,—but short of that necessary to melt the copper. The two first-named are run out together, as an alloy; leaving the copper in a *spongy* condition, still retaining the form of the original cakes. Some lead ores containing silver, which are not suited to the treatment by amalgamation, may be smelted,—and the resulting rich lead either cupelled, or treated by the

"PATTINSON PROCESS."—This process, the object of which is the concentration of the silver in the lead,—in order to avoid the necessity of cupelling so large an amount,—is based upon the fact that if a melted alloy of silver and lead in which the latter predominates, is cooled slowly, the crystals which form and sink are still poorer in silver. These crystals may be dipped out with a heated iron perforated ladle;—and the process repeated until the proportion of silver in the alloy becomes such that it melts at the same temperature as pure lead. In this case no crystals can separate. The operation is commenced in the centre one of a row of large cast-iron kettles, each set in its own fire-place. The crystals are ladled into the kettle on the left hand of the commencing one, until one-half its contents are transferred; the remainder is put into the right hand

one, and the commencing one is replenished with the original lead. This goes on, the crystals of each going to the one on the left, until,— at the end of the operation,—the kettle on the extreme right contains metal which is very rich in silver; while the metal in the one on the exteme left is almost wholly lead. The former is then cupelled.

THE "PARKE PROCESS" is another method of separating silver from lead, in which the silver-bearing lead, in fusion, is stirred together with melted zinc. The zinc and silver unite and rise to the surface. This alloy is skimmed off, and the zinc separated from it by distillation.

We will briefly allude to two other methods for the extraction of silver.

THE "AUGUSTIN PROCESS" is based upon the fact that the chloride of silver is soluble in a hot concentrated solution of common salt. The silver is chloridized by roasting the ore with salt. The chloride is dissolved in a hot solution as aforesaid, and the silver precipitated by metallic copper.

THE "ZIERVOGEL PROCESS" is founded upon the fact that *sulphate* of silver is soluble in *hot water*. The silver is converted into a sulphate by roasting, without salt. This sulphate is dissolved in hot water, and the silver precipitated, as in the Augustin process, by metallic copper.

Both of these last named processes have been employed in the treatment of copper matte containing silver.

REDUCTION OF COPPER SULPHURETS.

This is a tedious and expensive operation; owing to the fact that there are many different steps involved in it. It consists in a series of calcinations and smeltings. The process employed in Swansea, Wales, is as follows:

The "sorted" ore is first coarsely crushed with stamps, and then calcined. A large reverberatory furnace, eighteen feet long by fifteen feet wide, is charged with some three tons of it, through the "hopper" at the top of the crown or arch. This is spread evenly over the bed with rakes. A moderate heat,—not sufficiently great to fuse the surface, and thereby prevent volatilization,—is kept up. Every two hours the mass is raked over, and fresh fuel added. When all volatile matters have been driven off, which will be in about twelve hours, the heat is increased for a time; and the roasted ore is then discharged into the vault beneath. It is thence transferred to a melting furnace of about one-half the size of the first, called the "ore furnace." About one ton and a quarter is the charge. The heat is gradually raised to the melting point, and kept at that point for half an hour, to allow the "matte" to settle below the slag; and after some four or five hours, the melted coarse metal is discharged into a water tank, through a spout arranged for the purpose, while the slag is drawn into moulds at the back of the furnace. After cooling, the slags upon the tops of the cakes of metal at the bottom of these moulds, are broken off; and the metal added to that in the water-

tank, which has granulated. This metal is now roasted in a *third* furnace, at a high heat, for twenty-four hours; the result is a black friable mass, called "calcined coarse metal." This is mixed, for the *fourth* operation, with richer ore, containing silica; which forms, with any iron that may remain, a new slag, and the matte which results is cast into "pigs." In the *fifth* operation, some three tons of these pigs are piled upon the floor of a reverberatory furnace, and a quick fire got up. After a time the whole is melted, and the heat is lowered. It is now left to itself for ten or twelve hours; during which time, the crust which forms upon the surface is constantly swelling and bursting with the escape of gases. When this has ceased, the heat is again raised. A red heat is maintained for six hours, and then still farther increased, until complete fusion takes place; when the metal is run off at a tap-hole into moulds, as "blistered copper," leaving the slag.

The *sixth* and last operation is the refining, or toughening. The ingots are placed in a reverberatory furnace, and melted. After some eighteen or twenty hours, during which fusion is kept up, and oxydation has been going on, the surface of the mass is covered with powdered charcoal, and "polled," or stirred, with sticks of green birch wood, for twenty-five minutes; the charcoal being renewed as fast as it burns away. As soon as the metal becomes of the proper color and toughness, the stirring or polling is stopped. The proper time for this is determined by taking, from time to time, a small portion of the metal, and plunging it suddenly into water. The color and texture on a cut

surface are noted; and the degree of toughness is ascertained by bending it. The fire is again renewed; and after a time the copper is ladled out into moulds. It is then ready for the rolling mill.

Another method of smelting copper, is that by the blast furnace. The ore is first roasted; and then smelted in an upright furnace, about fifteen feet high, with charcoal or coke. The hearth is two feet square. Two basins, each three feet in diameter, at a lower level, receive the matte from the hearth alternately. The slags are removed, and the matte afterwards roasted in a reverberatory. This latter has a condensing chamber for the reception of those metals in the ore which are volatile. The operation of smelting the matte is repeated several times; after which it again goes through the blast furnace, and is finally refined in the reverberatory, or in a refining furnace specially constructed for the purpose. The ore generally contains sufficient iron to serve as a flux; in case it does not, iron must be added. The poorer ores are generally treated in the reverberatory;—the rich ores in the blast furnace.

An operation of a different character is as follows: The sulphuretted ore, after crushing, is mixed with nitrate of soda, and roasted with exposure to the air;—thereby being converted into a sulphate, which is soluble. The whole is put into a tank of water; and after the gangue has subsided, the solution is transferred to another tank, where the copper is precipitated by metallic iron.

REDUCTION OF LEAD SULPHURETS.

The reduction of galena,—the ore from which most of the lead of commerce is obtained,—is, essentially, a very simple process. A large proportion of the metal can be obtained without previous preparation of the ore, and without fluxes. In some of the Western States, the galena, which is there abundant, was formerly smelted in a simple square furnace, built of rough stones, or sometimes even of logs. On the floor of a furnace of this kind, was placed a layer of logs, and upon this a layer of split wood set up on end. The ore was then filled in upon the top of this, and covered with more wood. A fire was kindled at an opening in front, at the surface of the ground. By the time the ore reached the melting point, there was sufficient charcoal formed to take up the sulphur, and free the metal; which ran out at the opening, as fast as reduced, into a basin in front, placed at a little lower level. From this it was ladled into moulds for pig lead. In this way, fifty per cent. of metal was obtained from ore which contained eighty-five per cent.

But more perfect arrangements have taken the place of this. The furnace now in use is a reverberatory, with a hearth about six by eight feet in size, formed of old refractory slags; and the arch is about two feet in height. There is a tap-hole for the metal, and another for the dross. Several openings on each side serve for the admission of air, and also as work-holes. Wood is used as fuel.

The furnace is charged, through a hole in the top, with about a ton of ore, which has been picked over by hand, and freed from gangue. The heat is got up, the openings are all closed, and the whole allowed to sweat for two hours. Some fine charcoal is then thrown in, and mixed with the ore. The metal commences to form, and is drawn off into a basin below the tap-hole. The heat is then raised, and the ore constantly stirred. More charcoal is added as the supply burns out. This alternate tapping and charcoal-mixing continues until most of the metal in the ore has been yielded up. The heat is a dull-red, kept up mostly by the burning of the sulphur. At the last adding of coal, a few shovelsful of quicklime is also introduced, and a strong heat given. This brings out the remainder of the metal,—up to about seventy-five per cent. The operation occupies about four hours.

Galena is also smelted in upright blast furnaces. These are about seven feet high, and one foot or more wide. The fuel used is charcoal.

The *slag-furnace*, in which the broken-up slags from both reverberatory and blast furnace are re-smelted, is three feet high, and two feet square; with a cast-iron hearth inclined towards the front, so that the metal discharges itself as formed.

In English lead works, it is usual, after sorting the ore, to grind and wash it before smelting, for the purpose of concentration. The smelting is done almost wholly in reverberatories of peculiar shape; having a depressed centre, with a tap-hole at the lowest point. In France, iron ore is used as a flux, instead of lime; and the stiff slag afterwards treated in the slag-furnace already described.

In Germany, the ore, after being sorted, stamped and washed, is roasted, with salt or with iron. It is then smelted in a blast furnace twelve or fourteen feet high, and about fourteen inches square. Charcoal is used. The slag is from time to time carefully drawn off from the surface of the metal. At intervals of about eight hours, the furnace is tapped at the bottom, and the metal drawn off. Reverberatory furnaces are also used. In the Hartz mountains, an "elbow-furnace,"—a blast furnace of peculiar shape,—is in use. The ore is smelted with granulated cast-iron.

The lead obtained by these smeltings sometimes requires refining,—or "improving," as it is termed;—containing, as it does, various impurities,—such as antimony, tin and copper,—as well as silver. A reverberatory furnace built especially for the purpose, is used. The lead, while in fusion, is ladled into this furnace. The "scum," or pellicle, which forms on the top, is raked out as it gathers, at a door in the side of the furnace, so that a fresh surface is constantly exposed. In from twelve hours' time to several days, the lead will, on cooling, exhibit a crystalline appearance, which indicates its purity. A portion is occasionally taken out and examined, to determine when it has reached this state. It is then drawn off into an iron pot.

But the silver still remains. The process in use of late years for effecting its separation, is "Pattinson's." We have described this process under the head of silver reduction.

REDUCTION OF SULPHURET OF ZINC.

Zinc Blende, after being crushed and washed, is roasted in a reverberatory furnace for ten or twelve hours, and then *distilled.* Large crucibles, charged with the ore mixed with charcoal, are placed in a furnace of peculiar construction, and submitted to a steady constant heat for two or three days. The crucibles have each a hole in the bottom, from which an iron pipe leads to a receiver filled with water. The pipe is plugged with wood before the crucible is charged; and when the operation commences, it becomes charred sufficiently to permit the passage of the metallic vapor, but not of the ore itself. The metal is afterwards refined by smelting in large iron pots lined with clay, and cast in moulds.

Zinc Blende is exceedingly troublesome when in association with galena. The sulphur is separated from it with very great difficulty. It causes great loss of the lead in smelting; and if associated with silver ore, carries off more or less of *that* metal by evaporation. It is usual to separate blende from galena, as far as possible, before roasting, by crushing coarsely, and washing.

REDUCTION OF SULPHURET OF MERCURY.

The primitive methods employed for the reduction of cinnabar at the mines of Idria and Almaden, were based solely upon the heating of the ore; and were

performed with the rudest apparatus. The more scientific method involves the use of some substance in connection with the ore, for the separation, from it, of sulphur. Either lime or iron ore is generally used. The process in use in Bavaria, the apparatus for which was planned by Dr. Ure in 1846, is the most complete,—and may be described as follows:

Three large iron retorts, similar to those used in gas-making, are set in an arched brick furnace, with a fire-chamber beneath. They are protected from direct contact with the flame by fire-brick. They are of a size to contain one-quarter of a ton or more. The furnace is generally one of a series of three. A large iron pipe leads from the back of each retort into an iron condenser half-full of water;—and reaches just below the surface. The condenser is placed in a trough of cold water, and slightly inclined towards a cistern, into which it discharges the metal as it is distilled. The ore is coarsely powdered, and mixed with quick-lime.

Each retort is charged with about five cwt. of the mixture, and the fire started. A uniform heat is kept up, and a charge is worked off in about three hours. Instead of quick-lime, magnetic iron ore is often used;—and sometimes both together. If the metal was associated with zinc, or bismuth, these will be distilled over with it. It may be purified by re-distillation in a glass or iron retort, with one-fourth its weight of iron-turnings; or by digesting it in sulphuric or dilute nitric acid, which will dissolve the impurities.

PART V.

BLOW-PIPE ASSAY OF ORES.

Although the blow-pipe is of little use for the purpose of *quantitative* analysis or assay of ores,—that is, for the determination of the *amount* of any metal in a given mineral,—inasmuch as the test must necessarily be made upon so small a specimen,—it is nevertheless invaluable for *qualitative* analysis,—or the ascertaining the *presence* of that metal. Substances, the presence of which might essentially modify the process to be adopted for the working of an ore, but which could not be detected by a crucible assay, are by this means brought to light. It is also a useful auxiliary to the crucible assay, inasmuch as some of the operations connected therewith, such as cupellation of the button, etc.,—can conveniently be performed with the blow-pipe. Quantitative assays of *bullion* can be satisfactorily made with it;—as also, sometimes, of very rich silver ores.

The ordinary instrument used by jewelers, etc., is not suited for the purpose of the assayer. He requires one which is provided with a chamber for the reception of the condensed moisture from the lungs. The best

are made also with a platinum jet, and a mouthpiece of wood.

The flame of a candle, or of an alcohol or oil lamp, may be used. The oil lamp recommended by Berzelius, has a flat wick. A piece of fine-grained charcoal is generally used as a support for the specimen to be operated upon; where the object, however, is to observe the *color* produced in the flux, a platinum wire, bent at one end into a loop, is used instead. The substances most commonly employed as fluxes, or "re-agents," are borax, carbonate of soda, and salt of phosphorus,—or double phosphate of soda and ammonia,—sometimes called "microcosmic salt." A solution of nitrate of cobalt is also used. The borax is used in the form of *glass*, as already described.

When the flame of a candle or lamp is directed by a blast with the blow-pipe placed just above the wick, a long pointed *blue* flame is formed. This is the flame at the tip of which we hold any metallic oxyd which we wish to *reduce* to metal. If the blow-pipe is so held that the blast directs the *whole* flame upon the specimen, and covers it with its *extreme* tip, the specimen,—if a metal,—is *oxydized*. The first is termed the "*reduction*" flame, and the other the "*oxydation*" flame. By means of the blow-pipe, we not only throw the flame in any direction desired, but we intensify the heat with the blast. This blast must be continuous and steady. Some practice is required to give facility in this. The cheeks are kept distended, while the breath is drawn through the nose; the force given is only the natural contractility of the muscles of the cheeks.

QUANTITATIVE ANALYSIS.

We have said that the blow-pipe was of little use in making quantitative assays of ores. Yet as very rich ores *may* furnish an appreciable grain of metal, it may sometimes be desired; and as this chapter would scarcely be complete without a brief description of the process, we give it before entering upon the subject of the discrimination of minerals.

A portion of the ore is very finely pulverized in a small agate mortar. Of this, one grain is accurately weighed out. We will suppose the simple balance which we described in a former chapter, to be used. Our largest weight is one grain. We balance that weight, placed upon the 10 mark at one end of the beam, with the assay powder on the 10 mark at the other end. The point of a knife may be used as a spatula for transferring the powdered ore, in minute quantities, from the mortar to the point required. A steady hand is necessary. When the weighing is accomplished, a piece of paper may be slipped under the end of the beam to receive the ore. A hole sufficiently large to contain it, is now drilled in a piece of charcoal. The paper upon which the ore lies, is taken up, and if loosely doubled, is easily emptied into the hole. A grain or so of pulverized borax-glass is added to cover it. The reduction flame is carefully directed upon it, until the whole is melted into a button. This is cooled, freed from the slag, and cupelled with three grains of pure lead in fine filings, under the oxydation flame. The cupel may be an entire one, placed upon the char-

coal, or made of the crumblings of a crushed one, in a cavity in the charcoal.

The weight of the silver globule which remains after the cupellation, is the weight of the metal in the ore. We place it upon the 10 mark of one end of the beam. We will suppose that the grain weight, which balanced the original ore at the 10 mark of the opposite end, now balances the button at the 1 mark. The button weighs, then, one-tenth of a grain.

There are 29,166 ozs. troy in a ton of 2,000 lbs. avoirdupois. If the grain of ore had been *wholly* metal, there would then have been that number of ounces of metal per ton; but it is only *one-tenth* metal. We multiply, then, by one-tenth,—or, .1. So, also, if it had been .15,—or .152,—of a grain; those figures would constitute the multiplier. We have, then, this *rule* for cases

Where one grain is taken as the assay sample:

RULE.—Multiply the weight of the button in grains and decimals of a grain by 29,166. The product will be the weight, in troy ounces and decimals of an ounce, of metal in one ton of ore of 2,000 avoirdupois pounds.

The amount of metal per ton in the present case, is, then, 2916.6 ozs. This is either silver, or an alloy of silver and gold. We have before given a rule for determining approximately the proportion of gold and silver in a globule which is too minute to be submitted to the process of "parting." If it is one-fourth gold, it turns black, and the silver slowly dissolves, leaving the gold; if it is more than one-fourth gold, it turns black, but the silver is *not* dissolved; etc., etc.

The balance which we have described may be used also in the assay of gold bullion. The largest, or grain weight, is taken as the assay unit; and the three weights, used as we have directed, will give the three figures denoting, in thousandths, the fineness of the globule.

A method of determining the weight of a minute globule, is by the *scale*. This may be thus described: Two divergent lines, about six inches long, drawn upon an ivory plate, and cut at equal intervals by cross-lines, are sufficiently far apart at the point of greatest divergence to contain between them a globule large enough to be weighed upon a balance. The weight of this globule is noted upon the plate opposite the upper cross-line, and the weight of the smaller globules which would be contained between the divergent lines at the other cross-lines, calculated from it;—for they must evidently bear a certain mathematical relation to each other,—supposing the material to be always the same. The weights, as calculated, are noted in like manner with the first. All that is necessary, then, in weighing a globule, is to place it, with the forceps, between the divergent lines, and move it down towards the point made by the said lines, until it touches both of them;—the weight can then be read off at the side. For placing the smallest globules, the aid of a microscope is necessary.

QUALITATIVE ANALYSIS.

Two little operations which are considered a part of the blow-pipe analysis, are,—the examination of the

specimen,—first, in a glass tube, open at one end,—and, second, in one open at both ends. As these properly precede the other operation, in a systematic assay, we will speak of them before going on to the use of the instrument.

Examination in a glass tube open at one end only.

For this, a common test tube, or a matrass, may be used. In it, the specimen is heated over a spirit lamp. Several points may be determined by this. Thus, the substance may give out a gas or vapor. This may, for instance, be sulphurous acid; in which case a little piece of litmus paper,—(paper colored by a vegetable blue),—will be turned red by it,—showing its *acid* character; while at the same time the smell of *sulphur* will be perceptible. This shows the presence of a *sulphate* or a *sulphite*. If it is sulphuretted hydrogen,—the peculiar odor of which is well known,—the presence of some sulphuret containing water, is indicated. If it is ammonia, it is recognized by its odor, and by its turning litmus paper which has been reddened by a weak acid, back to a *blue* color;—showing an *alkaline* reaction. This would indicate either an ammoniacal salt, or an organic substance. If it is nitrous acid, it is known by the orange-red fumes, and acid reaction, and shows the presence of a *nitrate* or *nitrite*. If it is carbonic acid, it will cause a drop of lime water to become turbid; this shows a *carbonate*. The drop of lime water may be suspended from a watch crystal to make this test. If it is oxygen, it will re-light a match just extinguished, if a spark still remains;—this shows a peroxyd, or a chlorate, etc.

Some substances, again, yield a white sublimate, which condenses in the colder part of the tube; as, for instance, the chlorides of mercury. The oxyd of antimony melts to a yellow liquid, which vaporizes, and is deposited in shining *needle-shaped* crystals; arsenous acid, in *octahedral* crystals. Bi-sulphuret of iron,—(iron pyrites,)—gives a yellow sublimate; sulphuret of arsenic, a red one; sulphuret of mercury,—(cinnabar),—one which is black,—but which is red on being scratched with a knife. Selenium gives the peculiar smell of that substance, resembling that of rotten horse-radish; arsenic, the smell of garlic.

Examination in a tube open at both ends.

The specimen is in this case placed in the tube, about half an inch from one end. This is held over the spirit lamp; the other end being slightly elevated. As the air becomes heated, it escapes from the upper end, while fresh air enters at the lower. The effect is to *calcine* the specimen. For many substances, this is the most satisfactory test; volatile oxyds being formed which would not be formed in a closed tube. Arsenical pyrites,—(mispickel),—sublimes in minute octahedral crystals, which may be driven from one place in the tube to another, by moving it about over the lamp. Metallic bismuth is oxydized, and the oxyd condensed and afterwards fused to brownish globules.

These examples will serve to give an idea of the points to be determined by these operations. The blow-pipe is sometimes employed in connection with the tubes. We hasten on to those methods of examination

which more especially involve the use of that instrument.

Examination on charcoal alone.

Charcoal, as a support, not only assists the heating of the assay-piece, but it is in itself a re-agent; it aids reduction, by taking up oxygen from the oxyd to be reduced. The substance to be examined should be first pulverized.

The points to be especially noticed, in an examination on charcoal alone,—that is, without fluxes,—are: the smell of the gases which escape, and the appearance of the rings of *coating* which form on the charcoal, around the substance under examination, and which consist of oxyds. Thus, *arsenic* volatilizes without first melting, and shows a *white* ring or coating on the charcoal,—surrounding the assay-piece, but at some distance from it,—which may be produced by either the oxydation or the reduction flame. This coat is volatile, and can be easily driven away by the flame, giving the odor of garlic. *Antimony* easily fuses, and shows also a white ring, which is nearer the centre than that of arsenic, is less volatile, and gives no such odor. *Lead* easily melts, and gives, in both flames, a sulphur-yellow coat, which colors the reduction flame light blue. *Zinc* is easily fused. In the oxydation flame, it burns with a brilliant greenish-white color. The coat is yellow while hot, and white when cold; and is not driven away. *Cadmium*, in the oxydation flame, emits brown fumes, which coat the charcoal. The coat is reddish-brown when cold; in thin layers, orange-yellow. *Tin*

gives a coat which is close to the assay-piece, not volatile, and white when cold. *Silver*, when played upon for some time with the reduction flame, gives a slight dark-red coat. *Selenium* fuses with brown fumes, and deposits a steel-gray coat, which disappears under the reduction flame, with a smell of rotten horse-radish; giving the flame at the same time a blue color. *Tellurium* gives a white coat, with a red or dark-yellow edge, which gives a greenish color to the flame.

Examination on platinum.

If a platinum wire, bent at one end to a hook, is heated red-hot and touched to the powdered assay-substance, a portion of that powder adheres to the hook, and may be examined with the inner flame. Different salts, when thus examined by the *inner* flame, give to the *outer* flame different colors. If it is a salt of soda, the color will be reddish-yellow; it one of potassa, violet; of lithia, a fine carmine-red. Sulphate of baryta colors the outer flame yellowish-green; some arsenates color it blue; some salts of lead give it an intense azure-blue color; some of copper, an emerald-green. These appearances are variously modified by other salts which may be present.

Examination with borax and salt of phosphorus.

Many metallic oxyds can be dissolved by these substances used as fluxes; giving a peculiar color to the *bead* which is produced. The powdered assay-substance is *roasted* by treating it, on charcoal, alternately

with the oxydation and reduction flames, until the odor of sulphur or of arsenic ceases to be perceptible. It is then fused into a bead with the flux; in most cases on the platinum wire. Silica, alumina, lime and magnesia produce with borax, in either the oxydation or reduction flame, a colorless bead; the oxyds of lead and antimony, in the oxydation flame, one which is yellow while hot; the sesqui-oxyd of iron, in the same flame, one which is red while hot, and yellow when cold; the sesqui-oxyd of manganese, a violet one in the oxydation flame; oxyd of cobalt, in both flames, a blue one; oxyd of copper, in the oxydation flame, one which is green while hot, and blue when cold;—and in the reduction flame, one which is colorless while hot, and red when cold.

The colors given under the same treatment with salt of phosphorus, are in many cases the same with those exhibited when borax is used.

With carbonate of soda on charcoal, in the reduction flame, the oxyds of gold, silver, mercury, antimony, arsenic, bismuth, copper, iron, tin, zinc, and some others, are reduced to metal. Arsenic and mercury vaporize immediately; antimony, lead, and zinc, form coatings. Lime and magnesia are insoluble; the soda is absorbed by the charcoal.

We will now describe the behavior of the most common sulphuretted ores,—under the blow-pipe, and in the glass tubes; taking them in the order in which they were named in Part I of this work; abbreviating, for convenience' sake, the words "*Oxydation flame*" to "*Ofl*,"—and "*Reduction flame*" to "*Rfl*."

***Common Iron Pyrites*, heated in a tube closed at one end, usually emits sulphuretted hydrogen,—recognized by its odor,—and gives a sulphur sublimate.** The substance remaining is attracted by the magnet. In the *Ofl*, on charcoal, the sulphur burns off with a blue flame, and leaves red oxyd of iron. This gives, in the *Ofl*, with borax on platinum wire, a bead which is red while hot, and yellow when cold; and in the *Rfl*, a bottle-green bead. The shade of color varies with the amount of oxyd used for the experiment,—both in this case and others.

The behavior of *white iron pyrites* is similar to the above.

Magnetic Iron Pyrites, if heated in a tube open at both ends, emits sulphurous acid, but gives no sublimate. Like the first-mentioned, it is changed by the *Ofl*, on charcoal, to red oxyd. In the *Rfl*, it melts, and is covered with a black magnetic coating, which on a newly-broken surface shows a yellowish crystalline structure.

Arsenical Pyrites gives, first, in a tube closed at one end, a red sublimate of sulphuret of arsenic, and afterwards a black one of metallic arsenic; in the open tube, it yields arsenous and sulphurous acid, which are recognized by the garlic and sulphur odors. On charcoal, it gives the white ring coating at some distance from the piece tested. It sometimes contains cobalt. This may be detected by heating the assay on charcoal in the *Rfl*, until everything volatile has been driven off, and then fusing with borax in the *Ofl* into a bead,

which will be colored blue by cobalt. If iron is present, this bead will be green while hot. Oxyd of copper will render the blue color less perceptible; but if the specimen be heated in the *Rfl* until that oxyd is reduced, the color becomes distinct.

Copper Pyrites.—This mineral, if heated in a tube, one end of which is closed, decrepitates; and sometimes gives a faint sulphur sublimate, becoming at the same time iridescent. In the open tube, it gives out sulphurous acid. It blackens on charcoal, but becomes red on cooling. If the heat be continued, it fuses to a black magnetic globule, the fracture of which is reddish gray. It is reduced to copper and iron with carbonate of soda on charcoal.

Purple Copper behaves like the above.

Copper Glance.—This does not volatilize in the closed tube; but in the open one gives sulphurous acid. On charcoal, alone, it melts, and throws off glowing particles; while the outer flame shows a blue color. It is reduced to metallic copper with carbonate of soda.

Gray Copper.—This, which is a combination of copper, iron, zinc, antimony and arsenic,—with sometimes silver and mercury,—melts in the closed tube, and gives a dark-red sublimate, which is a sulphuret of antimony. In the open tube, it melts, and gives thick fumes of antimony, arsenous and sulphurous acid; mercury, if present, condensing in the upper part of the tube. On charcoal, it gives the antimony and zinc coatings. The

latter, if moistened with solution of nitrate of cobalt, takes a fine yellowish-green color in the *Ofl.* Silver, if present, may be detected by melting the assay-piece on charcoal in the *Rfl*, with borax and metallic lead, to a button. This button is treated with the *Ofl* until nothing remains but the lead and silver, (with gold if present,) and then cupelled. A little cupel may be made for the purpose, by boring a hole in the charcoal, and filling it with a paste made of moistened bone-ash with a small quantity of carbonate of soda. The surface is made smooth and slightly concave by pressing it with the end of a small pestle. After being dried by the spirit lamp flame, it is ready for use.

Galena, if heated in the closed tube, yields a white sublimate in small quantity. In the open tube, it emits sulphurons acid. On charcoal, it gives a globule of metallic lead, with the coatings of sulphate and oxyd of lead.

Zinc Blende evolves sulphurous acid if strongly heated in an open tube. In the *Rfl*, on charcoal, it usually gives first a dark coat of oxyd of cadmium,—that metal generally accompanying zinc; this is followed by the zinc coat. On charcoal, with carbonate of soda, it is reduced to metal, showing the greenish-white flame, characteristic of zinc.

Silver Glance, if treated with the *Ofl*, on charcoal, puffs up, emits sulphurous acid, and at last yields metallic silver.

Ruby Silver (Pyrargyrite), which is a combination of silver, antimony and sulphur, melts in the closed tube, and gives a sublimate of ter-sulphuret of antimony. It gives antimonial and sulphurous fumes in the open tube. On charcoal, it melts, and gives a coat of antimonous acid. With carbonate of soda, in the *Rfl*, it yields metallic silver. Sometimes it contains arsenic instead of antimony; in which case it gives the characteristic coat with soda on charcoal in the *Rfl*.

Brittle Silver Ore (Stephanite) decrepitates in the closed tube; then fuses, and yields a sublimate of sulphuret of antimony. On charcoal, it gives a coat of antimonous acid. Under the *Ofl*, the coat after some time becomes red, and a globule of silver is obtained. If arsenic is present, it gives a crystalline sublimate of arsenous acid in the open tube.

Cinnabar, heated in the closed tube, volatilizes, and condenses to a black sublimate, which by friction becomes red. Heated with carbonate of soda, it yields globules of metallic mercury. In the open tube, it is partially decomposed, giving metallic mercury and sulphurous acid. A very minute quantity of mercury may be detected by introducing into the tube an iron wire wrapped with gold leaf. This will turn white if the smallest quantity of mercury be present. On charcoal, it is completely volatilized, if pure.

Gray Antimony (Stibnite) volatilizes on charcoal, giving a coat, which if touched with the *Rfl*, disappears with a greenish-blue tinge.

A few additional tests may here be given:

Sulphur.—A test for sulphur, by which a very minute quantity may be detected, is thus performed: The substance to be tested is pulverized, mixed with two parts of carbonate of soda and one of borax, and fused on charcoal, with the *Rfl.* It is then powdered, placed upon a clean silver coin, and moistened with a drop of water. If there is the least particle of sulphur in the assay substance, a black spot will be formed on the coin, showing sulphuret of silver.

Horn Silver.—This ore, which is a *chloride* of silver, is of a pearl-gray or greenish color, semi-transparent, and so soft as to be easily marked with the finger-nail. On exposure to the air, it becomes brown. It melts in the flame of a candle. It is insoluble in water, and in nitric acid; and is easily reduced on charcoal with carbonate of soda.

Arsenic, in combination with sulphur, may be shown by mixing the assay substance with carbonate of soda and cyanide of potassium, and heating it gradually to redness in a tube closed at one end. Metallic arsenic will be deposited in the colder part of the tube.

But we have not space to continue the subject. The examples which we have given, have mostly been of cases where the substance was by itself; in which the test was comparatively simple. But where several different metals are combined in a single ore, the reactions interfere with each other; and the test becomes much more complex. Those who may desire to continue the

study, will find a most valuable aid in "*Elderhorst's Blow-pipe Analysis.*" In that work, tables are given, with the most notable changes that take place under various circumstances; and also minute instructions for the systematic examination and discrimination of minerals by means of the blow-pipe.

This book, and all the apparatus necessary for blow-pipe experiments, including complete sets of re-agents, can be had in San Francisco. For those tests, which we have detailed, the articles required will be: the blow-pipe, carbonate of soda, borax-glass, salt of phosphorus, litharge, pure lead,—(for the manner of preparing which we have given directions),—glass tubes open at one end and at both ends, a small agate mortar, forceps, do. with platinum points, platinum wire, litmus paper, a magnifying-glass, a magnet, a piece of charcoal, and a small hammer.

We may add, for the benefit of those persons who find a difficulty in acquiring the requisite facility in the art of keeping up a continuous blast with the ordinary assayers' instrument, that a patent blow-pipe is for sale in San Francisco, which has attached to it an elastic bag, as an air reservoir. With that instrument,—we are told,—the beginner finds no trouble, but enters at once upon experiments which in ordinary cases are only attempted after long preliminary practice in the use of the instrument.

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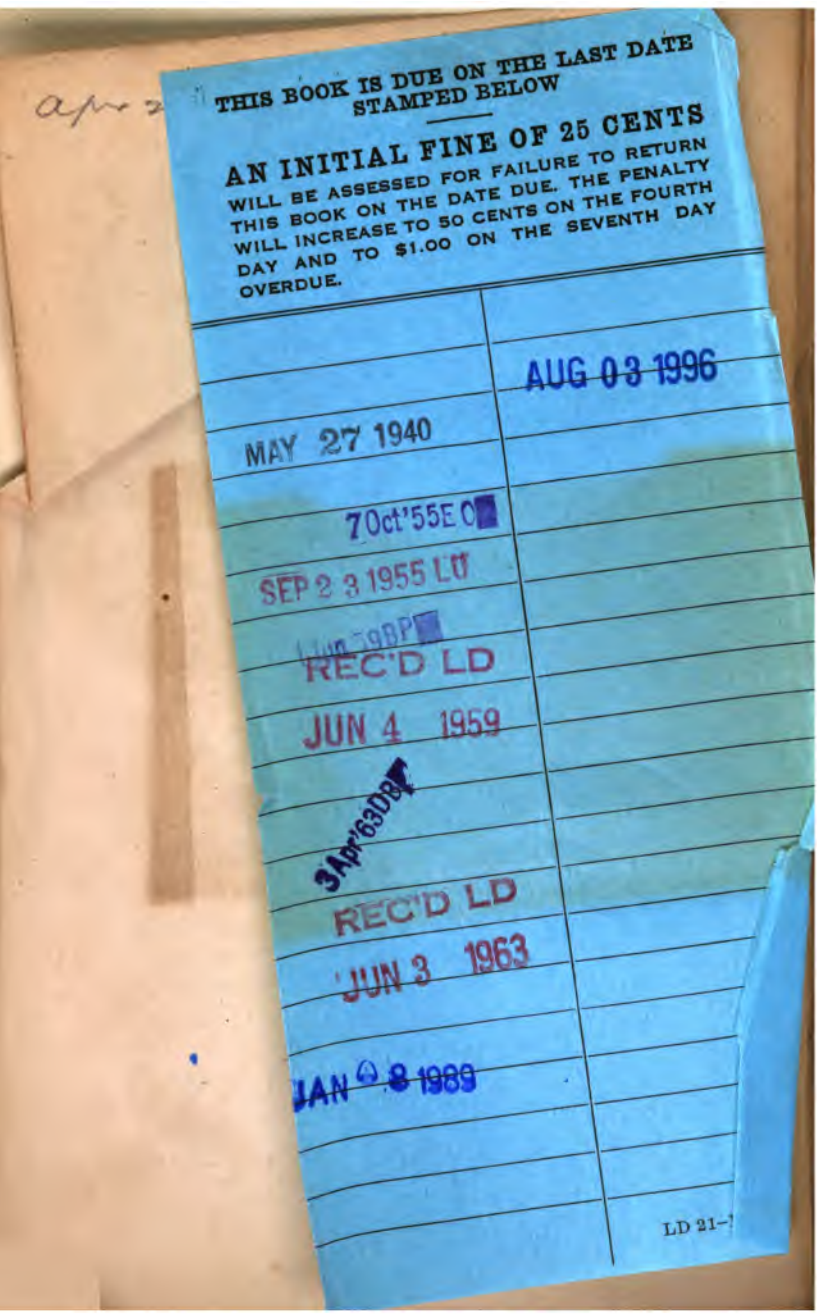
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